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MTC-TDR-63-4

RADAR 3.16 ACCURACY EVALUATION

Technical Documentary Report No. MTC-TDR-63-4

Air Force Missile Test Center
Air Force Systems Command
Patrick Air Force Base, Florida

21 FEBRUARY 1963

(Prepared under Contract No. AF 08 (606) 5300
by Systems Analysis RCA Service Company
Missile Test Project, Patrick Air Force Base, Florida)

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MTC-TDR-63-4

ASTIA DOCUMENT NO. AD____________

SYSTEMS ANALYSIS TECHNICAL REPORT NO. 25

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21 February 1963

Contract No. AF 08(606)-5300

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FOREWORD

RCA Systems Analysis Technical Report No. 25

Grateful acknowledgement is given to Mrs. R. Renegar for invaluable assistance in preparation of this report.

This Abstract is Unclassified

ABSTRACT

Accuracy and tracking performance of the Atlantic Missile Range AN/FPS-16 radar No. 3.16, located at Grand Bahama Island, is evaluated from data collected during two typical missile tracking operations.

The results show that the instrument performance was quite consistent with specified capabilities but that operational circumstances and extraneous factors may give rise to apparent systematic errors of sizeable magnitude. The issue of confounded flight test data can be prevented by appropriate editing of the radar measurements, based on recognition and correct interpretation of the errors.

This technical documentary report has been reviewed and is approved.

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1.0 INTRODUCTION

The following study of the AMR radar 3.16 falls into the category of evaluations concerned with the radar accuracy and tracking performance under field conditions, i.e. during live missile tests. The results of these evaluations are intended to provide the data users with realistic displays of radar data quality and to identify systems capabilities in the interest of best utilization and recognition of problem areas.

The accuracy determinations are based on comparisons between radar measurements (Azimuth, Elevation, Slant Range) and translated data from a reference system of distinctly higher accuracy level (in the case of this study, the AMR AZUSA MK.II system furnished the reference data).

The radar 3.16 analysis proved valuable for the dual reason that it demonstrates the basic radar's performance and, in addition sheds light on various error contributing factors which are typical of field operations but are less likely to occur in the course of controlled systems tests. Thus, while the radar's technical performance showed consistency with nominal capabilities and testified to proficient operation by the crew, the following items prompted specific attention as they entered the aspects of operational commitments, technical procedures, and data utilization:

a) The propagation in the launch area direction suffers from multipath interference which supports systematic Azimuth errors and larger than usual Elevation noise. In consequence, the use of radar 3.16 data at Elevation angles below 2.5° is objectionable since no corrections can be applied.

b) Correctable Range errors were caused by changes of the reference oscillator frequency to adjust the time sequence of beacon interrogations in multi-station beacon sharing. This problem is solved by a phasing modification which "jumps" the time relationship and does not require reference oscillator frequency shifts.

c) Delayed transfer of echo track between separating targets caused the radar data to exhibit large errors relative to the reference data. This type of operational event requires deletion of the data referring to the transfer and identification of the tracking reference in the published data.

d) The omission of parallax correction between the radar and AZUSA tracking reference led to the appearance of a systematic radar Range error in the data from one test. This problem can be alleviated by translating all data with respect to a common reference point on the target.

2.0 SUMMARY

The errors in radar 3.16 data (Range, Azimuth and Elevation) were evaluated from measurements during Tests No. 4507/61 (Beacon Track) and No. 120/62 (Skin Track) and partial evaluations from other tests.

The most important results are listed in Table I, whereas a more detailed breakdown is given in the body of the report.

TABLE I

Summary of Errors During Missile Track by Radar 3.16

Error	Test 4507 (Beacon Track)	Test 120 (Skin Track)
Standard Deviation (Total Error about Constant Mean)	80 to 280 Second N = 454	70 to 210 Second N = 280
$\sigma\Delta A$	0.006^{o} (0.11 m̸)	0.022^{o} (0.39 m̸)
$\sigma\Delta E$	0.011^{o} (0.20 m̸)	0.018^{o} (0.32 m̸)
$\sigma\Delta R$	7 feet*	21 feet
Bias (Magnitude of Constant Mean)		
$\overline{\Delta A}$	0.004^{o} (0.07 m̸)	-0.017^{o} (0.30 m̸)
$\overline{\Delta E}$	0.017^{o} (0.30 m̸)	0.003^{o} (0.05 m̸)
$\overline{\Delta R}$	- 182 feet*	3 feet

* Obtained from the time period 100 to 138 seconds: N = 380 (See paragraph 4.4).

In addition to the data describing the instrumental accuracy, the evaluation produced evidence that the radar measurements contained several apparently systematic errors. Close investigation revealed, however, that these errors were primarily a matter of operational circumstances rather than of radar systems performance. Appropriate measures in data processing are able to prevent these from entering the final flight test data reports.

3.0 DESCRIPTION OF TEST CONDITIONS

3.1 TRACKING OBJECTIVES AND TARGET CHARACTERISTICS

Radar 3.16 [AN/FPS-16], located at Grand Bahama Island with the geodetic coordinates

Latitude:	26° 36' 54.984"
Longitude:	78° 20' 53.188"
Height above Mean Sea Level:	46.38 ft.

participated in Tests 4507/61 and 120/62 for the purposes of metric data acquisition and as AZUSA MK. II back-up in generating metric data and furnishing real time data input to the Impact Predictor. While in both tests the targets were long range ballistic missiles, the Test 4507 vehicle carried a C-Band beacon as tracking aid, whereas the Test 120 vehicle was echo-tracked.

3.2 BEACON SPECIFICATIONS

The beacon system employed in Test 4507 is characterized by the data listed in Table II.

TABLE II

Beacon System

PARAMETER	QUANTITY
Antenna type	Recessed stub (Unipole)
Antenna pattern	Dual lobe, tailward direction gain G max. $\simeq$ 3 db at approximately $\pm$ 30° aspect from normal.
Attitude during flight	Stable
Beacon type	Avion 149-C
Pulse width *	90 yards
Internal delay *	280 yards
Power level *	51 - 58 db at R $\approx$ 3,700 yards

* Measured by Radar 1.16 (Cape Canaveral) prior to test.

3.3 TRACKING COVERAGES AND DYNAMIC REQUIREMENTS

Radar 3.16 data were evaluated from track during the flight intervals listed below.

TEST	TIME
4507	53 seconds to 330 seconds
120	70 seconds to 210 seconds

The radar coordinate positions for the above time portions are shown as time variables A(t), E(t) and R(t), in figures 1 and 2. Likewise, the dynamic tracking requirements (rates and accelerations) are displayed in Figures 3 - 6. Finally, the extreme rate values are listed in Table III.

TABLE III

Dynamic Tracking Requirements

COORDINATE	TEST 4507	TEST 120
$\dot{A}$ max.	1.55°/sec.	1.05°/sec.
$\dot{A}$ min.	0.01°/sec.	0.03°/sec.
$\dot{E}$ max.	0.50°/sec.	0.53°/sec.
$\dot{E}$ min.	-0.30°/sec.	0.05°/sec.
$\dot{R}$ max.	16000 ft/sec.	500 ft/sec.
$\dot{R}$ min.	-6000 ft/sec.	-3800 ft/sec.

The values listed in Table III are not only well within the AN/FPS-16 dyanmic capabilities, but will yield lag errors of less than 0.1 mil in angles and less than 10 feet in range with the servo bandwidths reportedly used during the investigated tests:

Angle System: Bandwidth: 1.2 - 2.5 cps

$K_v \simeq 284 \ldots 300$ sec.$^{-1}$

$K_a \simeq 3.6 \ldots 15.6$ sec.$^{-2}$

Range System: Bandwidth: 5 - 6 cps

$K_v \geq 4{,}000$ sec.$^{-1}$

$K_a \gtrsim 60$ sec.$^{-2}$

3.4 RADAR OPERATING PARAMETERS

During the investigated coverages, radar 3.16 was operated with the technical parameters listed in Table IV. According to present AMR procedures, the servo bandwidth settings were noted during the tests along the analog function recordings.

TABLE IV

PARAMETER	TEST 4507	TEST 120
PRF	142/71	285
Transmitter Power	330 KW	1000 KW
Transmitter pulse width	1 μ sec.	1 μ sec.
Antenna polarization	Linear - vertical	Linear - vertical
Receiver Noise Figure	11 db	11 db
Receiver IF Bandwidth	1.8 mc	1.8 mc
Pre-set Beacon Gate Delay	256 yards	N/A
Servo Bandwidth, angles	1.7 - 2.5 cps	1.2 - 2.4 cps
Servo Bandwidth, range	6 cps	5 - 6 cps

3.5 SELECTION OF TESTS

The radar 3.16 measurements from Tests 4507 and 120 were selected for the reason that these operations represent characteristic examples of this station's utilization and performance. Sufficiently long intervals of automatic beacon and skin track were covered to identify the radar's data quality in the categories of random and systematic errors and to recognize problems peculiar to station location and tracking geometry. The investigations were supported by data from several other tests.

3.6 REFERENCE STANDARD

AZUSA MK. II position data were translated at a sampling rate of 10/second to the radar 3.16 site as origin, transformed into radar coordinate data TAER, and thus provided the reference data required for determining the radar 3.16 tracking errors.

The qualification of the AZUSA data for reference purposes is illustrated by the first differences of AZUSA - originated T A'E'R' data and their comparison with time-coincident first difference of radar 3.16 data. Examples are shown in Figures 7 and 8 for the time interval 110 seconds of 120 seconds of Tests 4507 and 120. Examination of these data reveals that the smoothness of the AZUSA data exceeds that of the radar data by a factor of approximately 10, and the noise in AZUSA - originated reference data can be expected to contribute less than 3% to the apparent radar errors.

4.0 ERROR EVALUATION

4.1 DEFINITIONS

By definition, the accuracy of the data obtained from an instrumentation system is stated in terms of their differences from the true values. These differences represent the instrumental errors and are generally separated into the categories of random and systematic errors.

Random errors are chance variables and individually unpredictable. For numerical evaluation, they are assumed to be uncorrelated and to contain high-frequency components.

Systematic errors are generally continuous functions of various systems parameters and are amenable to calibration. These errors include correlated (cyclic) components in the low frequency domain, and bias as virtually zero frequency errors.

In evaluation of radar performance, the random errors are used as a measure for the data precision, whereas the system accuracy is stated by the total errors, which consist of bias (constant) and estimates of dispersion about the bias, calculated for the time span under investigation. The accuracy is stated in the above terms for the practical reason that the radar data processing normally takes into account only calibrations of constant value, whereas time varying changes of bias, e.g. due to dynamic lags, are corrected only in the processing of radar data accompanied by electronic error measurements.

4.2 RANDOM ERRORS

Estimates of random error were evaluated from the digital data second differences by means of the variate difference method, applied to spans of 21 successive data points. The results are displayed as time variables to demonstrate variations which may be related to the progress of track and associated target signal characteristics.

For Test 4507, Figures 9 - 11 show the random errors measured shortly after acquisition and during track at low elevation angles ($E \lesssim 4^{o}$, 50 to 80 seconds), where multipath effects degraded the radar performance. Figures 12 - 14 demonstrate the error trends from 80 to 330 seconds when the radar operated under good tracking conditions.

For Test 120, the random errors are displayed in Figures 15 - 17, covering the tracking interval from 70 to 120 seconds.

As a survey for the size distribution of the random errors, the estimates of dispersion are arranged in the form of cumulative distributions (Figures 18 - 19). The results are summarized in Table V below, listing the 50% and 84% levels of the data.

TABLE V

Random Error Magnitude

	Test 4507		Test 120	
MEASUREMENT	50%	84%	50%	84%
σA	0.002°(0.04$\not{m}$)	0.003°(0.05$\not{m}$)	0.003°(0.05$\not{m}$)	0.005°(0.08$\not{m}$)
σE	0.002°(0.04$\not{m}$)	0.003°(0.05$\not{m}$)	0.003°(0.05$\not{m}$)	0.004°(0.07$\not{m}$)
σR	9.9 feet	17.8 feet	15.8 feet	23.8 feet

To determine whether the above results can be considered typical for radar 3.16, the corresponding values from six other tests were assembled and are displayed in Figures 20 - 22. The data from Tests 4507 and 120 show that these operations yielded lower values for the angular noise than indicated by the weighted rms of the other tests, whereas the dispersions in range are not significantly different.

Even though the random errors are governed by target-dependent noise and radar-peculiar noise components, past evaluations have shown that the estimates of errors as obtained from the variate difference method are usually quite consitent with the magnitudes predicted from radar-dependent noise effects and thus may judiciously be employed for qualifying observed radar performance with respect to the systems design capabilities. On this basis, the random error magnitudes observed during Test 4507 and 120 are examined for agreement with the relationship:

$$\sigma_r = (\sigma_m^2 + \sigma_{th}^2)^{1/2} \tag{1}$$

where σ_r = random errors in radar digital data

σ_{th} = tracking noise due to receiver thermal noise

σ_m = mechanical error components (residual servo noise, data gear train errors, encoder granularity).

According to the systems specifications, the radar 3.16 mechanical noise components are assumed to be constant and independent of the tracking conditions with

$$\sigma_m \leq 0.045 \not{m} \tag{2}$$

whereas the receiver thermal noise contributions are given by:

$$\sigma_{th}(\theta) = \frac{\theta_B}{\left[2 \ S/N \ fr/bs\right]^{1/2}} \tag{3}$$

where θ_B = antenna half-power beamwidth ($\not{m}$)

S/N = I.F. signal-to-noise ratio (decimal units)

fr = P.R.F. (pps)

bs = servo noise bandwidth (cps).

Rearrangement of equation (3) yields the S/N ratio required for given thermal noise components and radar parameters:

$$S/N = \frac{\theta_B^{\,2} bs}{2 \text{ fr } \sigma_{th}^{\,2}} \tag{4}$$

Solving equation (4) for the radar 3.16 operating conditions and the average size of the observed data noise, we find the S/N requirements for the condition that σ_m is ignored:

a) For Test 4507, where bs = 3.5 cps, fr = 142 pps, and $\bar{\sigma}_{th}$ = .036 mil

$$\begin{aligned} S/N &= (400 \times 3.5) / (2 \times 0.0013) \\ &= 3{,}850 \\ &= 35.74 \text{ db} \end{aligned} \tag{5}$$

b) For Test 120, where bs = 2 cps, fr = 285 cps and $\bar{\sigma}_{th}$ = 0.053 mil

$$\begin{aligned} S/N &= (400 \times 2) / (2 \times 285 \times .0028) \\ &= 500 \\ &= 27 \text{ db.} \end{aligned} \tag{6}$$

The results (5) and (6) are now compared with the actual S/N observations in order to check the radar's internal performance and the mechanical noise contributions.

During Test 4507 the measured S/N ratio exceeded the value (5) of 35.74 db by 5 ... 15 db during the greater portion of the evaluated coverage (Figure 23) and consequently should have suppressed the thermal noise components to between 0.01 and 0.02 mil. Solving (1) for σ_m, we find:

$$\sigma_m = (\sigma_r^2 - \sigma_{th}^2)^{1/2}$$

$$= 0.03 \ldots 0.034 \not{m}$$

which demonstrates that the system performed well within the design criteria, (2).

For Test 120, the S/N ratio was generally lower than the value cf 27 db derived in (6) for exclusive thermal noise effects. Since the observed random errors are even smaller than can be attributed to thermal noise, no margin is left to evaluate mechanical contributions. This situation has been observed also at other radars under conditions of low angular rates. It is possible that the actually utilized servo bandwidth was narrower than registered, and a value of approximately 0.5 cps would have rendered better agreement. Nevertheless, in spite of the unfavorable signal conditions (Figure 24), the low data noise proves that the system performed also during this test well within tolerances.

4.3 TOTAL ERRORS

The total errors were obtained from the differences between time-coincident radar 3.16 and translated AZUSA MK. II measurements, carried out for as long as practical time intervals to reveal bias and long-periodic variations sufficiently distinguished from short-term errors.

The radar/AZUSA differences are shown with respect to time of flight in Figures 9 - 14, for Test 4507, and in Figures 15 - 17 for Test 120. Figures 25 and 26 present the distributions of the deviations for these data. The 50% level is an estimate for the bias of the evaluated data span, and the 84% level represents an estimate of one standard deviation (1σ) around that bias. Shown in Figure 27 is a composite plot of ΔA, ΔE and ΔR with a sampling rate of one data point/0.1 second for Test 4507. Power spectra of the AZUSA MK. II/radar differences were computed for the data span 50 - 250 seconds of Test 4507 and are shown in normalized form in Figures 28 - 30. Table VI lists the numerical results for bias and standard deviation as obtained from Figures 25 and 26 and the number of data points used for developing the cumulative distribution.

TABLE VI

Total Error Magnitudes

Error	Test 4507 (Beacon Track)	Test 120 (Skin Track)
Standard Deviation (Total Error about Constant Mean)	80 to 280 Sec. N = 454	70 to 210 Sec. N = 280
$\sigma\Delta A$	0.006° ($0.11\not{m}$)	0.022° ($0.39\not{m}$)
$\sigma\Delta E$	0.011° ($0.20\not{m}$)	0.018° ($0.32\not{m}$)
$\sigma\Delta R$	7 feet *	21 feet
Bias (Magnitude of Constant Mean)		
$\overline{\Delta A}$	0.004° ($0.07\not{m}$)	-0.017° ($0.30\not{m}$)
$\overline{\Delta E}$	0.017° ($0.30\not{m}$)	0.003° ($0.05\not{m}$)
$\overline{\Delta R}$	- 182 feet *	3 feet

* Obtained from the time period 100 to 138 seconds: N = 380 (See paragraph 4.4).

4.4 SYSTEMATIC ERRORS

In the processing and evaluation of data it is desirable that systematic errors be corrected and their effects upon final data minimized. Even though the AN/FPS-16 radar is designed with particular attention to small systems tolerances, small position data discrepancies of apparently systematic nature are frequently generated by factors extraneous to the radar. These are usually difficult to isolate and require tedious data interpretation and editing. While their majority would not have appeared in flight test data publication, they are contained in the evaluated data sets. The radar 3.16 data were deliberately compared in unedited form with the reference measurements to demonstrate the type of errors which may occur in typical tracking application and influence the overall data quality. In this respect, the radar 3.16 evaluation proved valuable in that it permitted identification and qualification of these non-radar-dependent anomalies.

Those errors which were identified as apparently systematic and which motivated detailed investigation are listed in Table VII below. The errors are separated into those which appeared to be radar dependent and those which were apparently caused by external circumstances. In view of the demonstrated quality of AZUSA MK. II data and the systematic error characteristics, no attempts were made to challenge the reference data as a potential error source. In addition to the topics listed in Table VII, the overall radar performance during both tests is discussed.

TABLE VII

Systematic Error Survey

TEST	TIME PERIOD	OBSERVATIONS	PARAGRAPH
		Radar Dependent Errors	
4507	54-310 seconds	Bias Components	4.4.1
4507	80-310 seconds	Cyclic Components	4.4.2
		Non Radar Dependent Errors	
4507	54- 80 seconds	Multipath effects in azimuth and elevation	4.4.3
4507	140,173,222 seconds	Temporary range errors	4.4.4
120	150-160 seconds	Radar position data departures associated with target separation and change of tracking reference.	4.4.5

4.4.1 BIAS COMPONENTS

Small amounts of zero set bias are considered normal in each operation and are removed by means of "orientation corrections" in post-flight data processing. Nevertheless, in the interest of minimal errors for real-time data utilization, the orientation is made as accurately as practical with particular attention to the angle coordinates.

For the radar 3.16 evaluation, the data bias values are represented by the average of the radar/AZUSA differences. The results $\overline{\Delta A}$, $\overline{\Delta E}$ and $\overline{\Delta R}$ are indicated in the displays, Figures 9-17.

During the early portion (54 to 80 seconds) of Test 4507 track, the radar was exposed to severe multipath problems whereas the latter portion (80 - 300 seconds) is more representative of undisturbed AN/FPS-16 track. The rather large variations of the radar/AZUSA differences during the early tracking phase (Figures 9 - 11) suggested that inclusion of these data might falsify determination of the most probable systems bias. Therefore, the time periods 54 - 80 seconds and 80 - 330 seconds were treated separately with the results listed in Table VIII below.

TABLE VIII

Angular Bias Measurements for Test 4507

MEASUREMENT	TIME PERIOD	
	54 - 80 Seconds	80 - 310 Seconds
$\overline{\Delta A}$	- 1.06 mil	0.07 mil
$\overline{\Delta E}$	1.52 mil	0.30 mil

During Test 120, relatively large angular dispersions ($\sigma\Delta A$ = 0.39 mil, $\sigma\Delta E$ = 0.32 mil) developed due to tracking under marginal signal conditions (low level, strong scintillations). **Nevertheless, exclusive of the target transfer period, the angular bias is small with**

$$\overline{\Delta A} = -\ 0.3\ \not{m}$$
$$\overline{\Delta E} = \ \ 0.05\ \not{m}$$

Experience in field application indicates values of angular bias may reach $\pm$ 0.2 - 0.3 $\not{m}$. The results from both tests, therefore, testify to careful systems alignment and operation within acceptable tolerances.

A bias of sizeable magnitude was observed in the range data of Test 4507, whereas the Test 120 data revealed a negligible range bias of only $\overline{\Delta R}$ = 3 feet. The range bias during Test 4507 was approximately -180 feet for the time period 50 to 180 seconds and -115 feet for the period 180 to 300 seconds with an over all average of -151 feet. Usual sources of errors of this size can be range zeroing of the radar's range tracker or corrections for the fixed internal beacon delay. Range zeroing errors, which can be caused by an ill-defined range calibration target, are likely to appear on a test-by-test basis. Examination of a number of orientations revealed, however, that this is not the case.

Based on the fact that radar 3.16 range measurements on other tests involving beacon track did not show a bias of similar magnitude nor indicated a general beacon delay correction problem, an inadvertent beacon delay overcorrection for Test 4507 is, therefore, suspected as the most likely cause for the average bias $\overline{\Delta R}$ = -151 feet.

Efforts were made to identify the cause of the gradual bias shift of approximately 65 feet which occurred near 180 seconds (See Figure 14). A smooth change of this type may be associated with (a) variation in internal beacon delay, (b) a change in the

AZUSA or radar data, or (c) the choice of different reference points on the missile for AZUSA and radar 3.16 track.

Ref. (a) Upon examination of the radar 3.16 function record and data from other stations, internal beacon delay changes were concluded to be the least likely cause of the range bias shift. This is validated by, (1) the known internal delay stability of the Avion 149-C beacon [$\Delta R_i \lesssim 5$ yards at the signal level variations, i.e. $\Delta S/N < 5$ db, observed during the time period 180 - 200 seconds], and (2) the absence of similar delay changes in the data of radar 1.16 for this same test.

Ref. (b) Investigation of both the AZUSA and the radar data did not reveal irregularities which would help to explain the bias shift. It needs to be mentioned however, that it is difficult to detect changes of this magnitude in the data trends due to the small effects of these errors upon the slope of the position data.

Ref. (c) Since conjectures (a) and (b) did not yield a satisfactory explanation, the effect of different tracking reference points on the missile was investigated. This condition manifests itself by an error behavior closely related to aspect geometry. For verification of this, the following hypotheses had to be satisfied:

1. The bias change must be consistent with the geometry established by the distance between reference points.
2. The relative errors should reach a minimum at $\theta = 90^\circ$ and display a trend which can be predicted from the function:

$$\Delta R = L \cos \theta$$

where L = distance between AZUSA and radar reference points

θ = aspect angle

ΔR = change in range error.

During Test 4507, small cyclic errors were observed in the azimuth and range data. The azimuth errors appear to be caused by a small eccentricity of the azimuth optical encoder mechanical drive as the variation is repetitive every 22.5° of azimuth rotation (the optical encoder is driven by a gear ratio of 16:1, resulting in $360^\circ/16 = 22.5^\circ/$ encoder revolution). The RMS value of the resultant error is:

$$\sigma\Delta A = 0.004^\circ (0.07 \text{ ₥})$$

The cyclic range errors observed during Test 4507 are typical AN/FPS-16 radar-dependent translation errors and usually show periodicity at 2000 or 4096 yard range increments. The errors repetitive at 2000 yard increments are typical for nonlinearities between mechanical rotation and electrical phase shift of the 82 KC phaseshifter whereas errors at 4096 yard increments are likely to be caused by a nonlinearity in the fine range encoder drive. The errors for Test 4507 appear repetitive at 2000 yard intervals and thus pinpoint the phase shifter as the most probable error source. To evaluate the magnitude of the effect of the phaseshifter nonlinearity, the dispersions of range data were calculated for the time period 100 - 138 seconds. Normally it is desirable to inspect a longer span but the shifts in range bias occurring after 138 seconds made it difficult to isolate the cyclic components adequately. The RMS error for the evaluated time span was found to be:

$$\sigma\Delta R = 7 \text{ feet}$$

Because the overall azimuth and range dispersions remained well within specifications ($\sigma\Delta A = 0.1$ ₥, $\sigma\Delta R = 15$ feet), no corrective adjustments to the radar were necessary in this respect. It should be noted that the quality of the AZUSA MK II position data, despite the long target distance from their origin, permits detection and analysis of errors to the degree indicated above.

For Test 120, the cumulative distribution (Figure 26) yielded the following dispersions:

$$\sigma\Delta A = 0.022^{\circ} (0.39\ \not{m})$$
$$\sigma\Delta E = 0.018^{\circ} (0.32\ \not{m})$$
$$\sigma\Delta R = 21 \text{ feet}$$

These dispersions are consistent with the signal conditions (5db $< S/N <$ 20db) encountered on this test (Figure 24). The large scintillations, which include complete loss of signal contribute to the oscillatory nature of the errors, in that when the signal reappears after a drop-out the radar error signals cause a transitory overshoot in tracking position. Thus the oscillatory errors of Test 120 may be catalogued under the classification of target-dependent tracking errors.

4.4.3 MULTIPATH EFFECTS

Multipath interference is the condition where the target return signal illuminates portions of the ground surrounding the radar even more strongly than the radar itself causing some of the energy to arrive at the radar over different paths.

The data of Test 4507 exhibits unusual errors in azimuth and elevation during the early tracking phase at elevation angles $E \lesssim 4^{\circ}$ (see Figure 27). Since over-water multipath interference normally introduces negligible azimuth errors, and elevation multipath errors are reduced to very small values at elevation angles $E \lesssim 2^{\circ}$, the observed errors were unexpected.

The radar was tentatively ruled-out as a probable error source since the analog error recording of Test 4507 (Figure 31) as well as those of Tests 5412, 6203 and 4502 did not indicate the presence of unusual errors. Further confirmation of non-radar-dependent tracking errors was provided, however, by the following results, established upon comparison of data from the four tests listed above.

(a) All tests have approximately the same error trends in azimuth and elevation during track at low elevation angles, i.e. (1) predominant azimuth errors and (2) elevation errors above $E \approx 2^{\circ}$ (see Figure 32), and

(b) all tests show a trend towards a maximum azimuth error at $A \approx 314^{\circ}$ (see Figure 33).

Careful examination of the above evidence results in the following conclusion:

> The cause of the errors appears to be ground clutter since:
>
> (1) The radar does not see the target under the true azimuth until higher than normal elevation angles are reached, and
>
> (2) the phenomenon is confined to low elevation angles.

This is indicative of the multipath disturbance caused by targets straddling the radar-to-target propagation path. It should be pointed out that a similar situation is regularly observed in the AMR launch area where surface structures produce sizeable azimuth errors when looking at a target located in a known direction.

From the radar site 3.16 clutter diagram (Figure 34), it is suspected that similar observations would be encountered also in other azimuth sectors. The observed error regularly noticed at A $\approx$ 314° stems merely from the fact that all missiles launched from Cape Canaveral appear in this direction.

A remedy for this problem could be sought only in clearing the radar area of potential reflectors. This, however, may be impractical, and the need for such an effort would depend on the importance of gathering data at low elevation angles. Unless this is established, data should not be committed to full performance ($\sigma\Delta A$, $\sigma\Delta E \leq 0.2$ mils) at elevation angles $E < 4°$, which for typical liquid propelled missiles corresponds to an elapsed flight time of 100-110 seconds.

Since this situation has been exploited only in the azimuth sector towards the launch area, controlled tests using aircraft should be conducted if low angle coverage is desired in directions where presently no information on this subject is available.

During Test 4507 the azimuth error reached a maximum of $-0.16°$ (2.8 mils) at 62 seconds whereas the maximum elevation error [$\Delta E = 0.22°$ (3.9 mils)] occurred at 55 seconds (see Figures 9 and 10). Both of these exceed the basic radar accuracy by a factor of more than 20.

For Test 120 the multipath effect is masked by the large errors:

$$\sigma\Delta A \approx 0.035° \ (0.62 \text{ mils})$$
$$\sigma\Delta E \approx 0.095° \ (1.7 \text{ mils})$$

caused by marginal signal conditions.

4.4.4 RANGE ERRORS DUE TO PHASING

Temporary range errors appeared at 140, 175 and 225 sec., during Test 4507, in the form of sudden bias changes and with values of $\overline{\Delta R} \cong -40 .. -50$ ft. These errors are strictly a matter of operational procedure as explained below:

To adjust the time relationship between successive beacon interrogations during multi-station operations, the radar's reference oscillator frequency can be changed and effect the delay or advance of the transmitter timing phase relative to that of the other radars. An undesirable side effect of this procedure consists of a change in range scale according to:

$$\Delta R/R = \Delta f/fo$$

where R = the radar-to-target slant range

fo = the reference oscillator center frequency

Δf = change of reference oscillator frequency and

ΔR = the range error.

The range errors which appear in the radar shaft data during phasing are:

$$\Delta R = (\Delta f) R/fo.$$

Inserting the value $\Delta f = 6$ c.p.s, used during Test 4507, we find:

$$\Delta R(140 \text{ sec}) = \frac{6(\text{cps})\ 550(\text{Kft.})}{81.959(\text{KC})} = 40.26 \text{ ft},$$

$$\Delta R(175 \text{ sec}) = 47.58 \text{ ft. } (R = 650 \text{ K ft.}) \text{ and}$$

$$\Delta R(225 \text{ sec}) = 50.51 \text{ ft. } (R = 690 \text{ K ft.}).$$

These errors, which can easily be corrected for known values of R and Δf, no longer appear in the AMR radar data, since the above analog phasing method has been replaced subsequent to Test 4507 by one which changes the relative phase within one P.R.F. cycle. This technique provides phasing control without any degrading effects upon the range data.

4.4.5 ERRORS DUE TO TARGET SEPARATION

Typically, skin track at site 3.16 involves the transfer of the radar from the larger first stage of the vehicle to the smaller second stage. During the time required to ascertain that separation has occurred and proper transfer action taken, sizeable errors may build up which are charged to the radar. The separation sequence is graphically displayed in Figure 35 and summarizes the complete transfer operation. The errors resulting during the time of transfer are:

$$\Delta A = 0.108^{\circ} \text{ (1.9 m/)}$$
$$\Delta E = -0.135 \text{ (2.4 m/)}$$
$$\Delta R = 1070 \text{ feet}$$

and are considered quite reasonable for the conditions involved.

It should be restated that S/N conditions for Test 120 were marginal resulting in difficult tracking environment. The elapsed time for the transfer was approximately 12 seconds (146 to 158 seconds).

5.0 DISCUSSION OF RESULTS

Although the evaluation becomes more tedious as a result of the variety of accuracy degrading effects, it is possible to retrieve realistic accuracy information and pinpoint error sources which are normally removed from specially designed tests. Considering only the radar-dependent errors of Test 4507 the very gratifying results are:

$$\sigma\Delta A = 0.006^{\circ} \text{ (0.11 m/)}$$
$$\sigma\Delta E = 0.011^{\circ} \text{ (0.20 m/)}$$
$$\sigma\Delta R = 7 \text{ feet.}$$

This excellent performance is masked by external factors which inflate the above statement of radar errors to an unreasonable degree. The majority of externally dependent errors will not be eliminated by smoothing or a constant correction and thus careful screening of data is necessary. Those factors which can be removed by data processing techniques, i.e. range phasing errors and range bias shift due to differences in reference points, are also errors which appear as radar errors but are not veritably chargeable to the radar. They were brought out in this report to emphasize to all data users the pitfalls which might be encountered by the use of raw data without consideration of external circumstances. With the installation of a "jump phasing" modification at 3.16 the range phasing errors will no longer occur in the raw data.

The removal of radar-dependent cyclic and bias errors are most important for full utilization of the radar's accuracy potential. Careful attention to range zero and beacon delay alignment will substantially contribute to bias-free real-time data. The correction of the cyclic error, however, requires the care of a laboratory type experiment to eliminate the minute mechanical error. Because of this, and the fact that the cyclic errors were well within tolerances, adjustments at this site were not undertaken.

Although the data employed in the calculations of power spectrum included the periodic error components (paragraph 4.4), the absence of peaks and the smooth decay of amplitude with frequency, reflects the high data quality of the beacon track. Peaking of sizeable magnitude is normally observed in other tests.

Test 120 was presented to demonstrate the excellent AN/FPS-16 echo tracking capabilities under very marginal tracking conditions. A S/N ratio of 12 db is considered necessary to ascertain reliable track, although the data quality will be less than optimum. Data at S/N $<$ 12 db are not committed however, to any specific quality, and utilization of the data for further processing is based on post flight data inspections. The errors, in spite of the low S/N and large signal scintillations, were quite small, except for the transfer period. The errors developed during target separation were the result of non-standard tracking conditions. The errors of Test 120, excluding those incurred during transfer, may be summarized as:

$$\sigma\Delta A = 0.022^\circ \ (0.39 \ m\!\!/)$$
$$\sigma\Delta E = 0.018^\circ \ (0.32 \ m\!\!/)$$
$$\sigma\Delta R = 21 \text{ feet.}$$

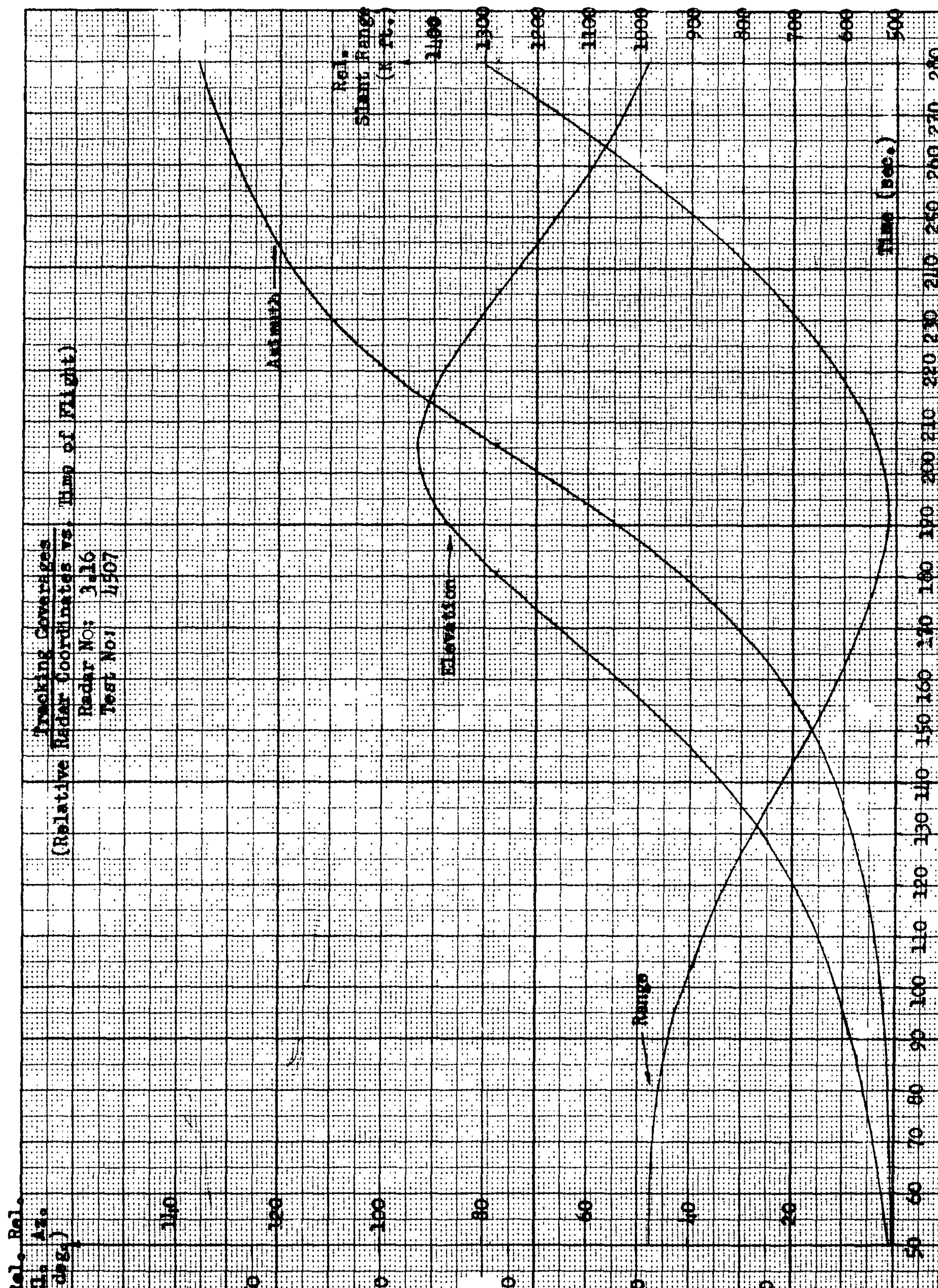
This evaluation did not isolate dynamic lags as a separate error contribution. As stated earlier, with the reported bandwidths used, only lag errors of less than 0.1 m̸ and 10 feet were to be expected. Judicious choice of bandwidths suiting the dynamic requirements during any given test will result in small lags similar to those listed above and, at the same time, minimize the random error amplitudes.

6.0 CONCLUSIONS

The analysis of operational tests provides a good description of the radar 3.16 accuracy under field conditions and, simultaneously, sheds light on station-peculiar effects which degrade the data quality independently of the radar's basic accuracy level. The evaluation, therefore, is considered valuable both from the accuracy and the systems application point of view.

The radar 3.16 random and total errors are consistent with predictable tolerances and good systems alignment. Whereas the appearance of a range bias beyond typical error magnitude appears to be a singular case, the low data dispersions achieved during Test 120 under quite unfavorable signal conditions and the small total errors during both tests demonstrates a high level of proficiency of the operating personnel.

FIG. 1



Tracking Coverages
(Relative Radar Coordinates vs. Time of Flight)
Radar No: 3.16
Test No: 4507
Azimuth
Elevation
Range
Rel. Slant Range (k ft.)
Time (sec.)
Rel. El.
Rel. Az.
(deg.)

FIG. 2

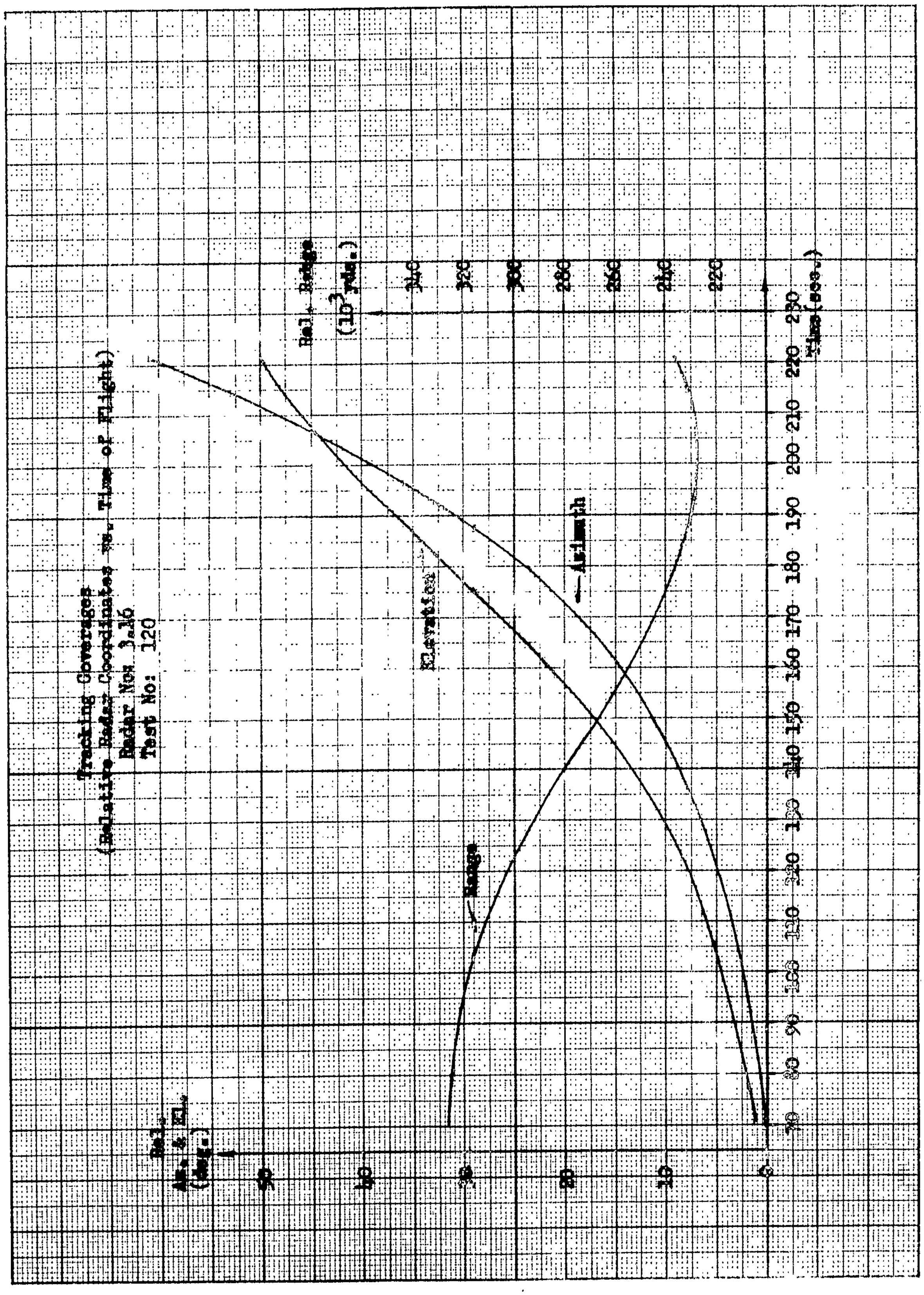
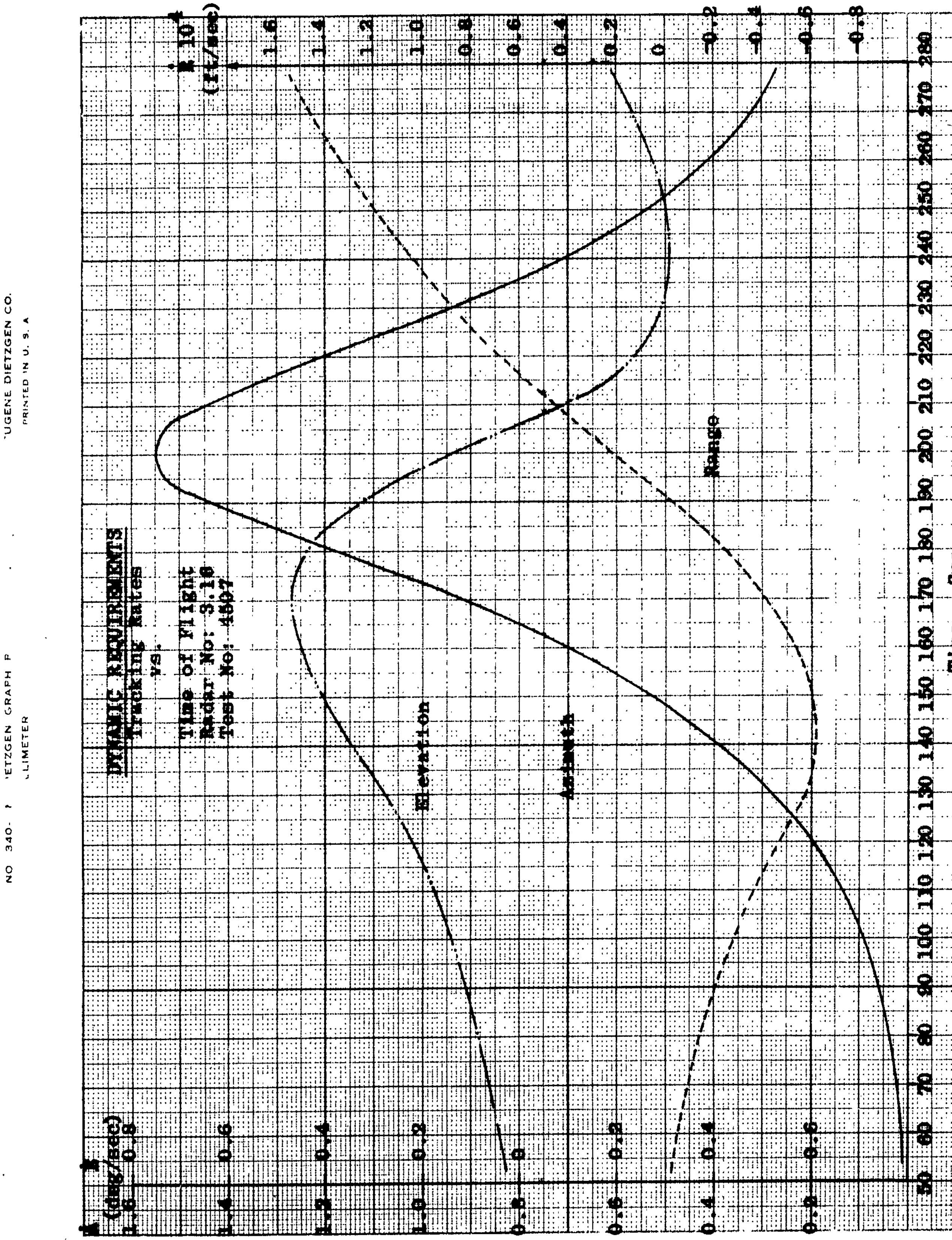

Tracking Coverages
(Relative Radar Coordinates vs. Time of Flight)
Radar No: 3.16
Test No: 120
Rel. Range (10^3 yds.)
Rel. Az. & El. (deg.)
Time (sec.)
Range
Elevation
Azimuth

FIG. 3


DYNAMIC REQUIREMENTS
Tracking Rates
vs.
Time of Flight
Radar No: 3.18
Test No: 4507
Elevation
Azimuth
Range
Time — Sec.
(deg/sec)
(ft/sec)

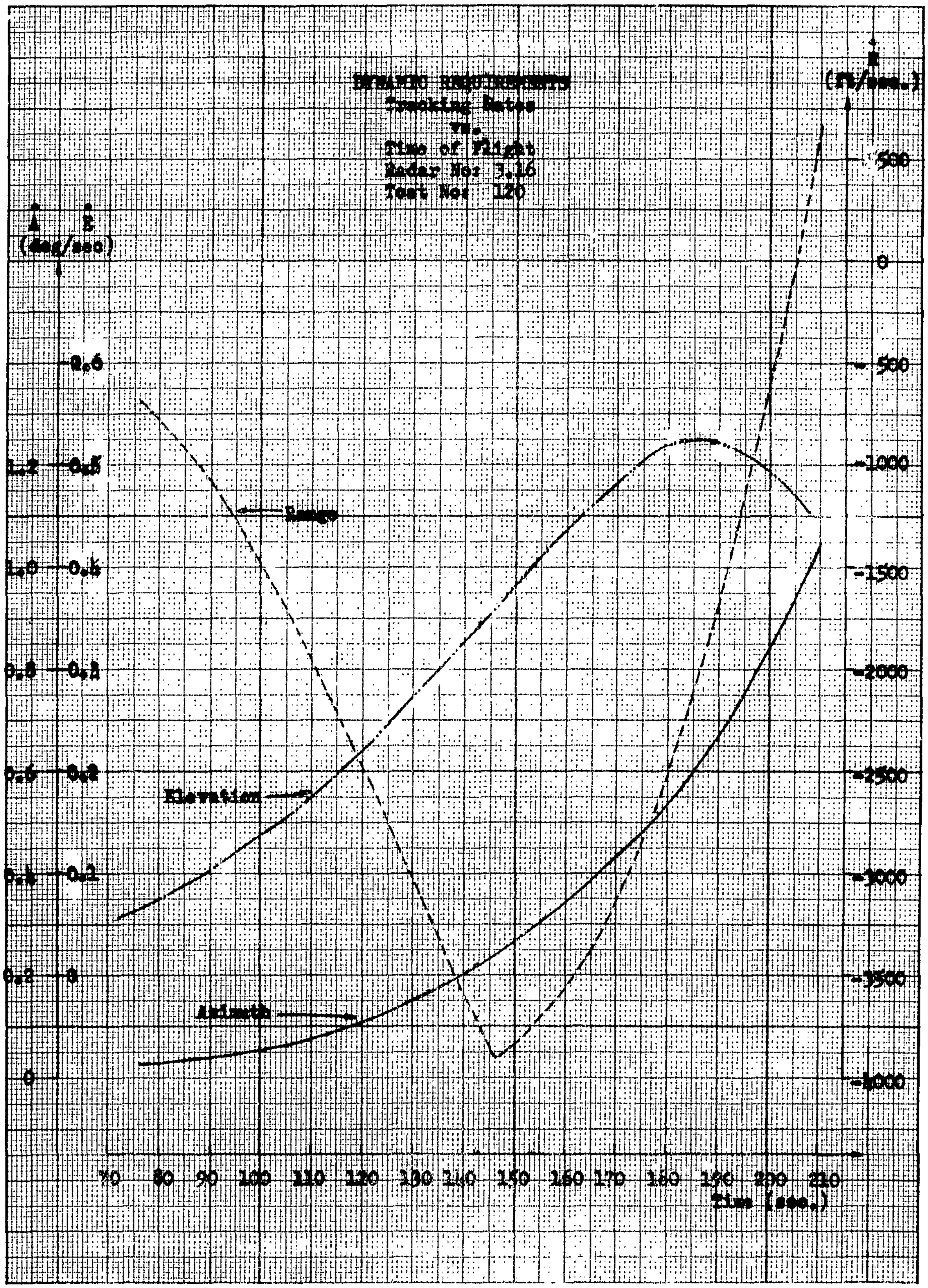

Tracking Rates
vs.
Time of Flight
Radar No: 3.16
Test No: 120
(deg/sec)
(Ft/sec.)
500
0
-500
-1000
-1500
-2000
-2500
-3000
-3500
-4000
0.6
1.2 0.5
1.0 0.4
0.8 0.3
0.6 0.2
0.4 0.1
0.2 0
0
Range
Elevation
Azimuth
70 80 90 100 110 120 130 140 150 160 170 180 190 200 210
Time (sec.)

FIG. 5

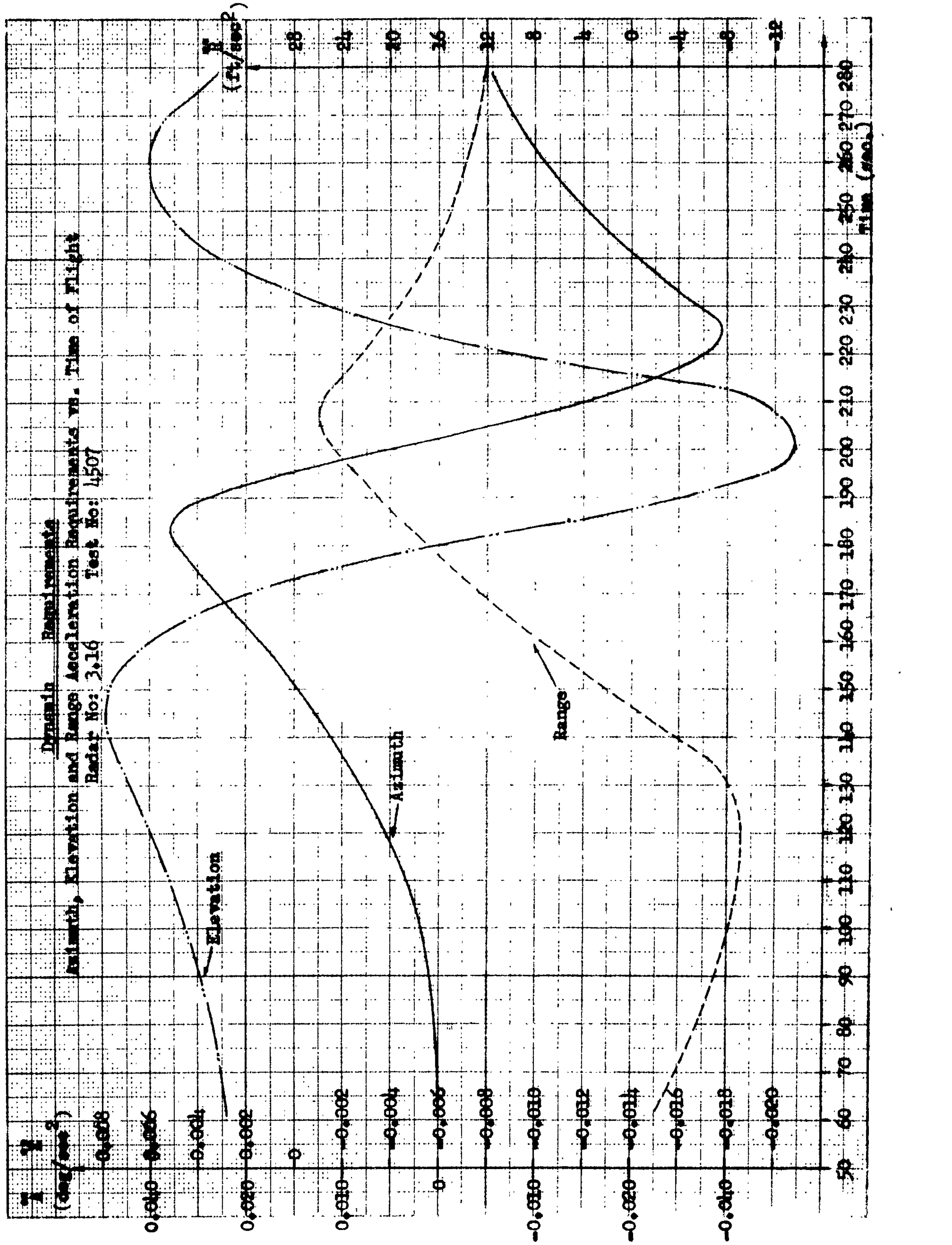
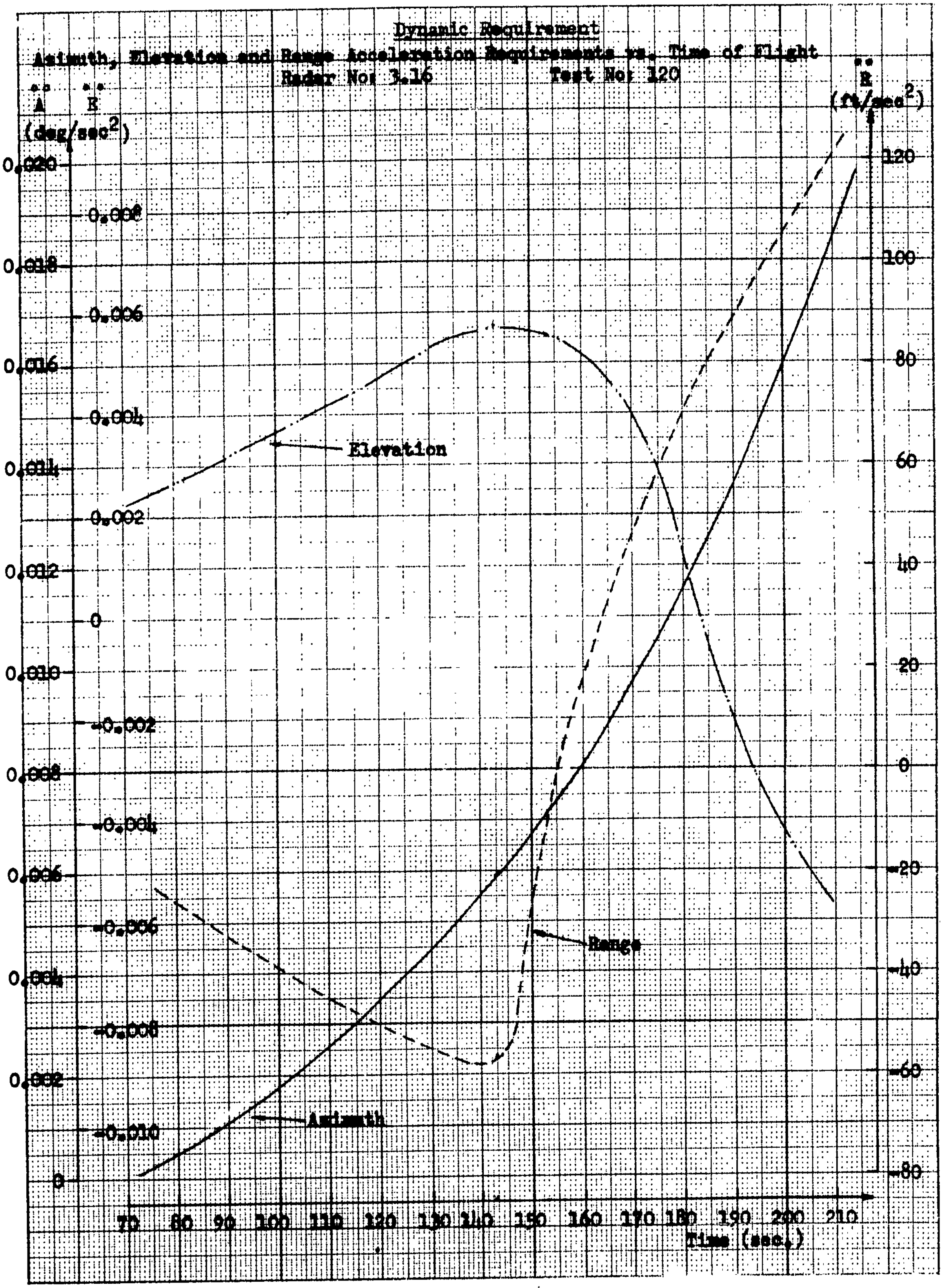

Dynamic Requirements
Azimuth, Elevation and Range Acceleration Requirements vs. Time of Flight
Radar No: 3.16 Test No: 1507
Elevation
Azimuth
Range
(deg/sec²)
(ft/sec²)
Time (sec.)

FIG. 6



Dynamic Requirement
Azimuth, Elevation and Range Acceleration Requirements vs. Time of Flight
Radar No: 3.16
Test No: 120
A E
(deg/sec²)
R
(ft/sec²)
0.020
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0
0.008
0.006
0.004
0.002
0
-0.002
-0.004
-0.006
-0.008
-0.010
120
100
80
60
40
20
0
-20
-40
-60
-80
Elevation
Range
Azimuth
70 80 90 100 110 120 130 140 150 160 170 180 190 200 210
Time (sec.)

Comparison of Radar and Azusa (Translated) 1st. Differences
Test No: 4507/61
Radar No: 3.16

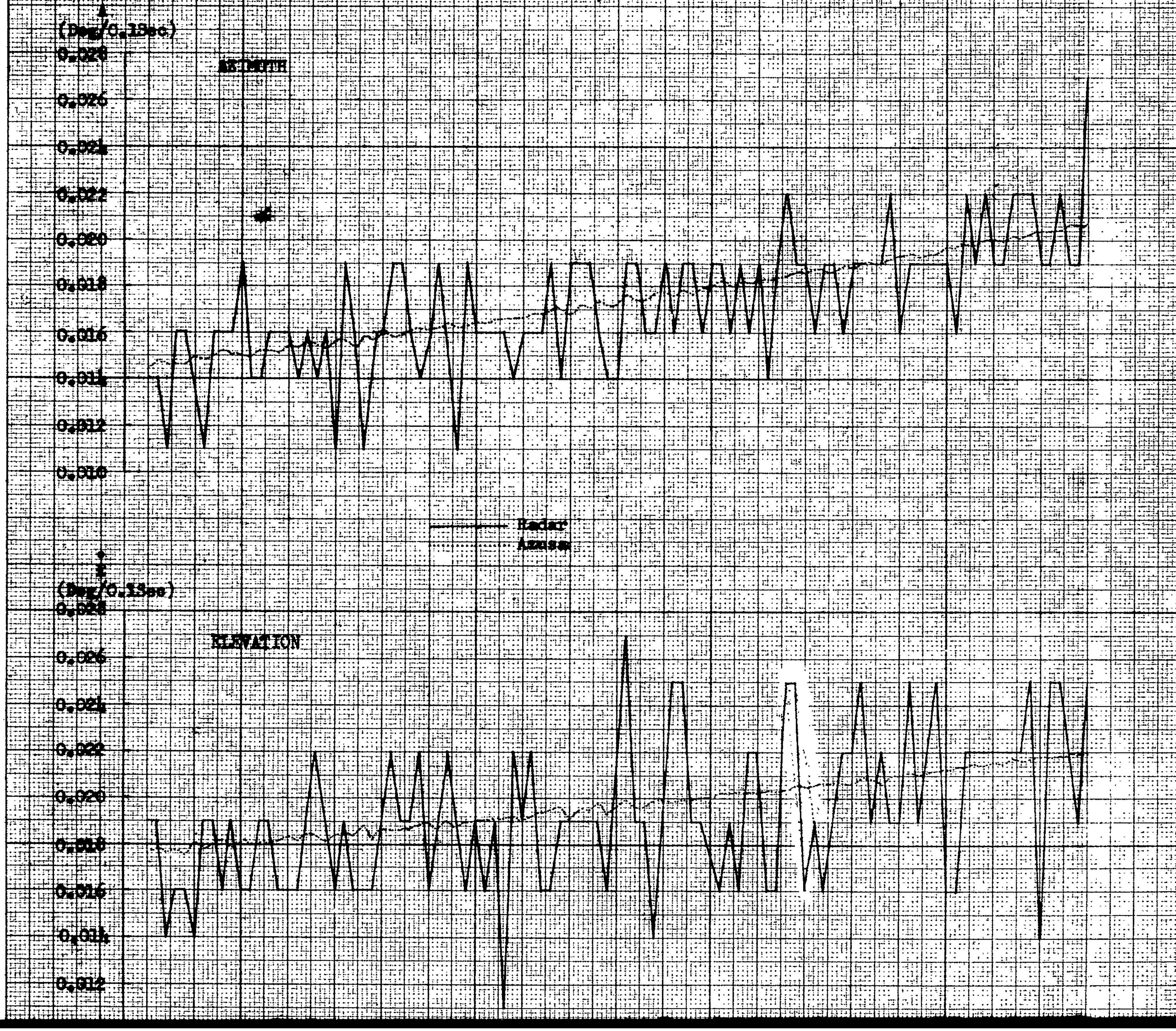
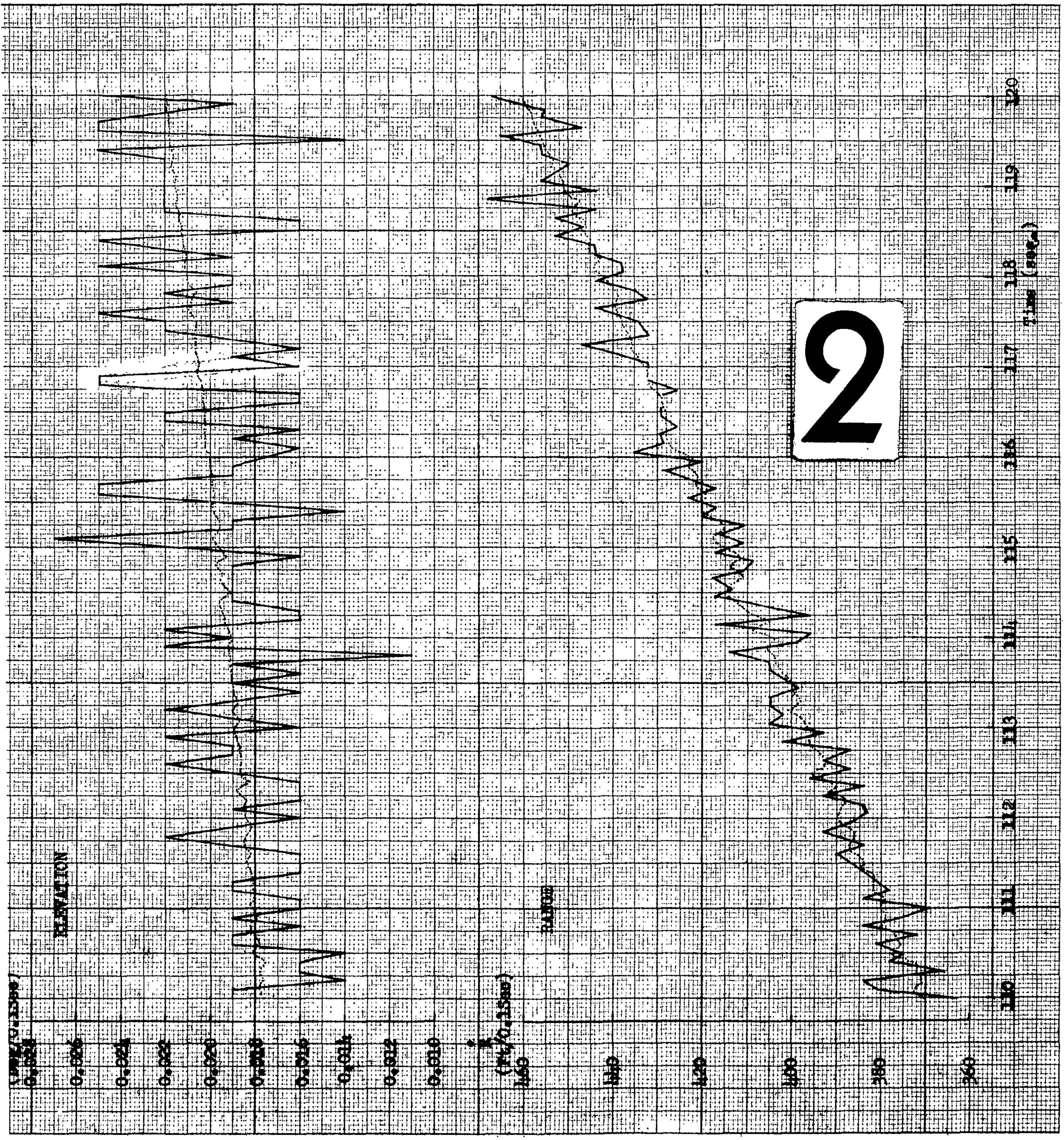
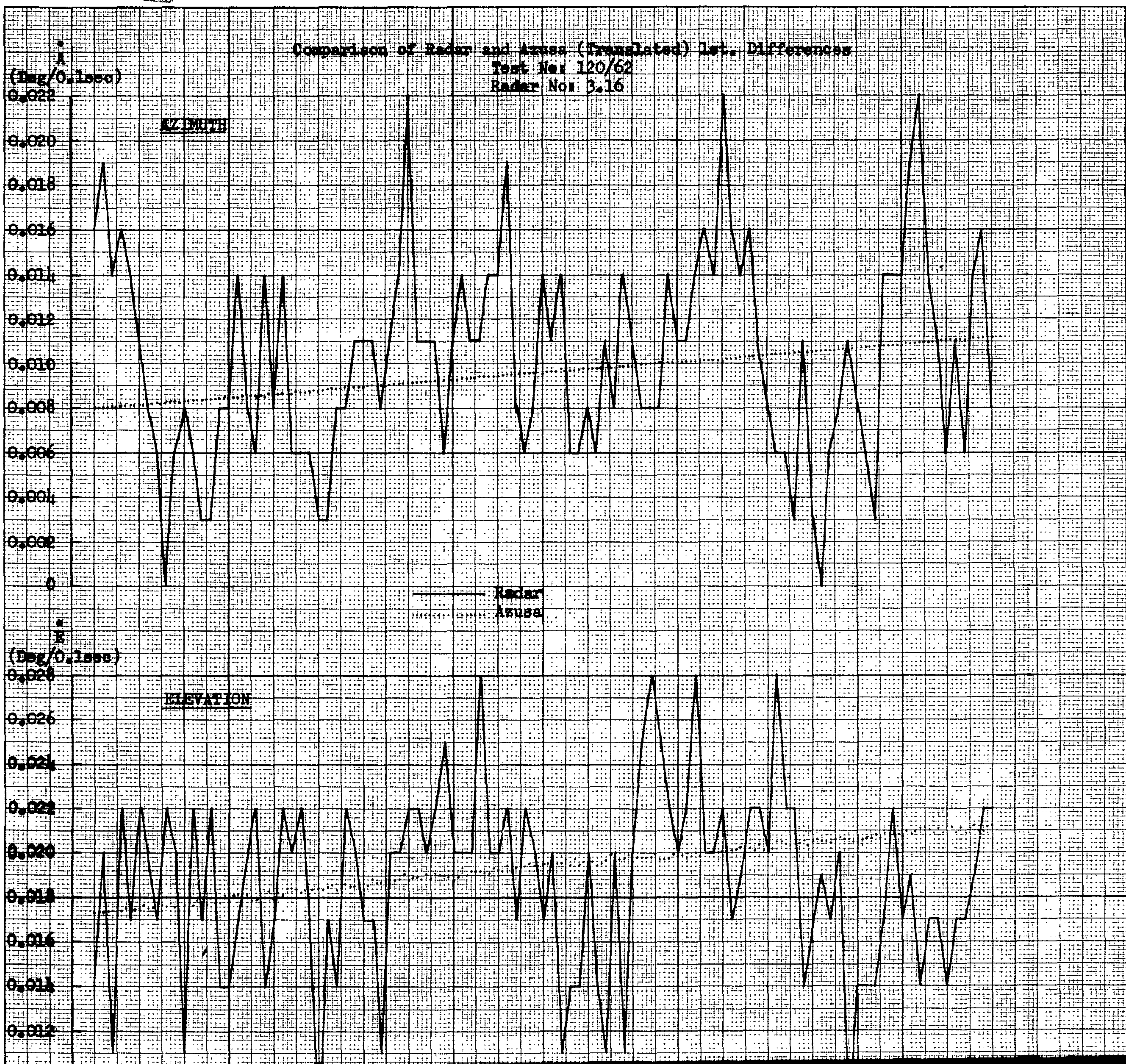


FIG. 7


ELEVATION
RANGE
Time (sec.)
110
111
112
113
114
115
116
117
118
119
120
2

Comparison of Radar and Azusa (Translated) 1st. Differences
Test No: 120/62
Radar No: 3.16



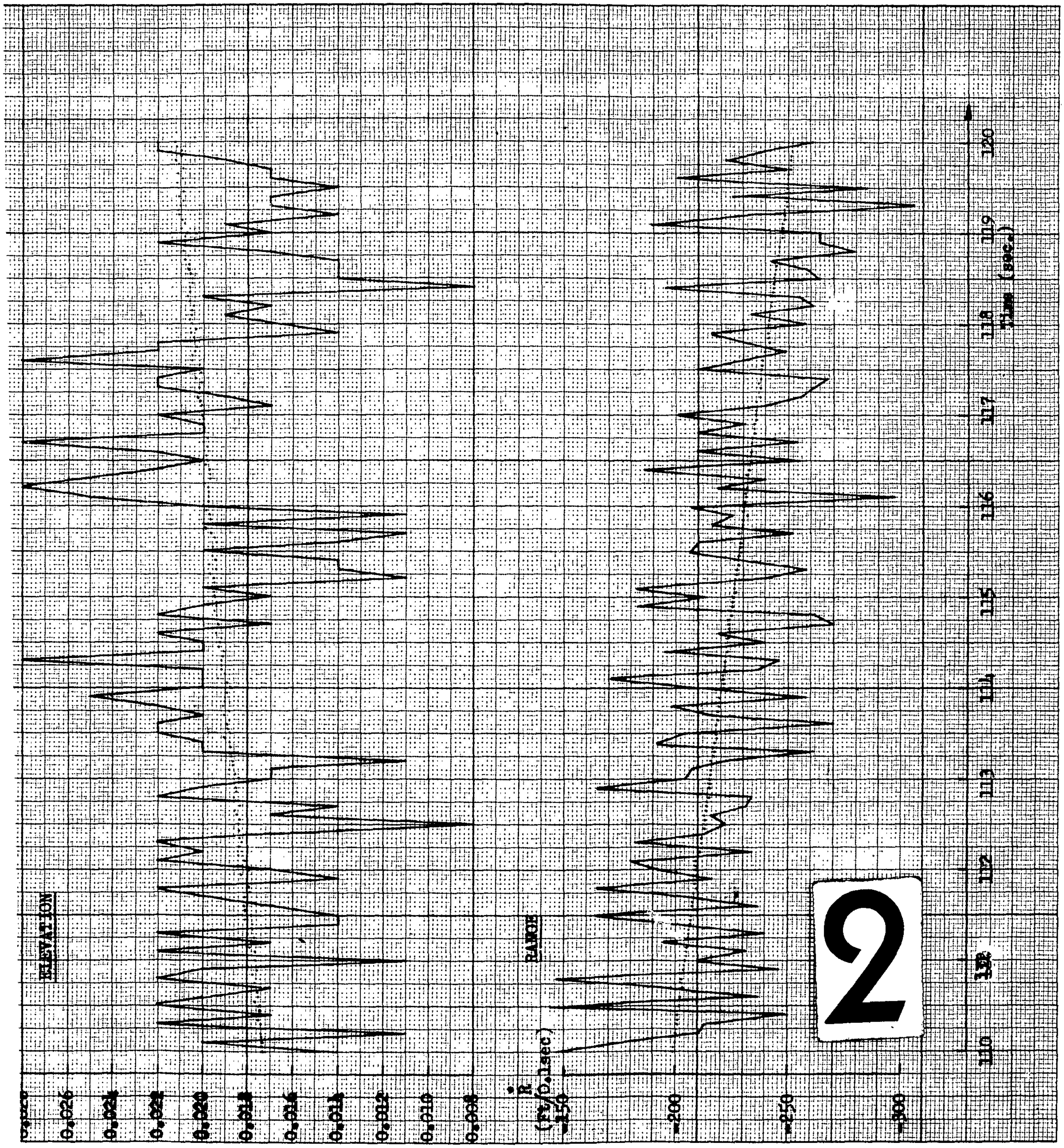
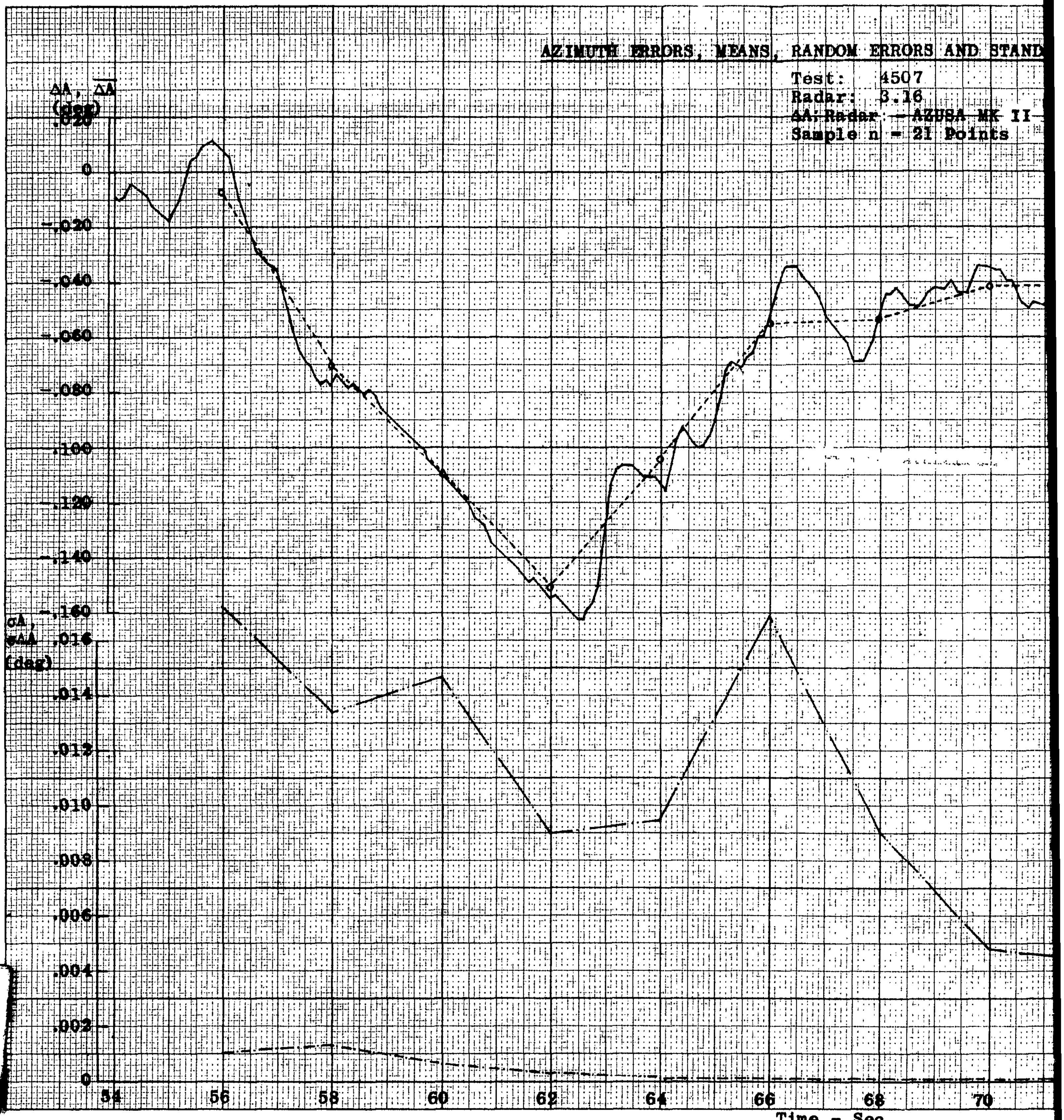
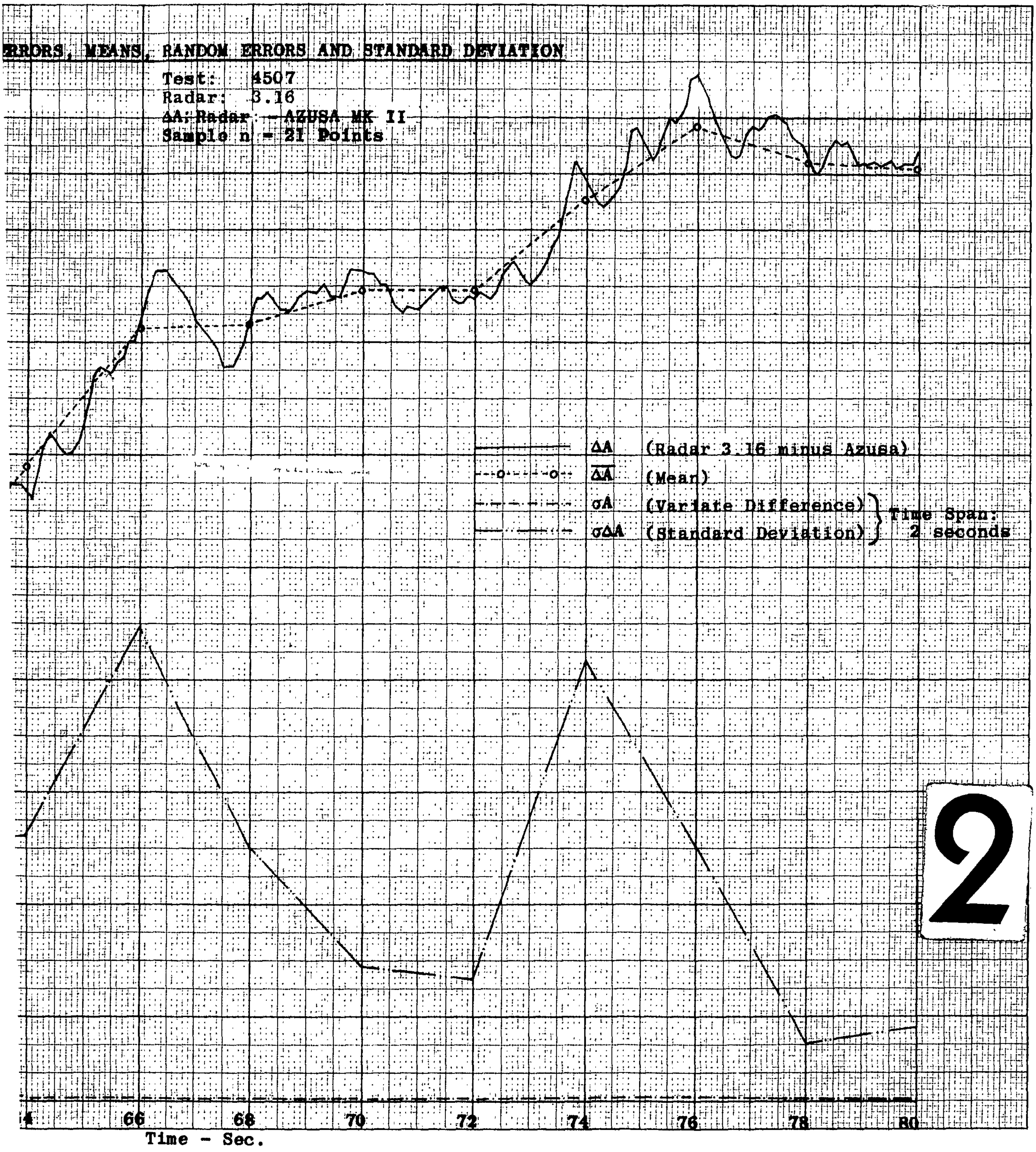

ELEVATION
0.026
0.024
0.022
0.020
0.018
0.016
0.014
0.012
0.010
0.008
RANGE
Ṙ (ft/0.1sec)
-150
-200
-250
-300
110
112
113
114
115
116
117
118
119
120
Time (sec.)

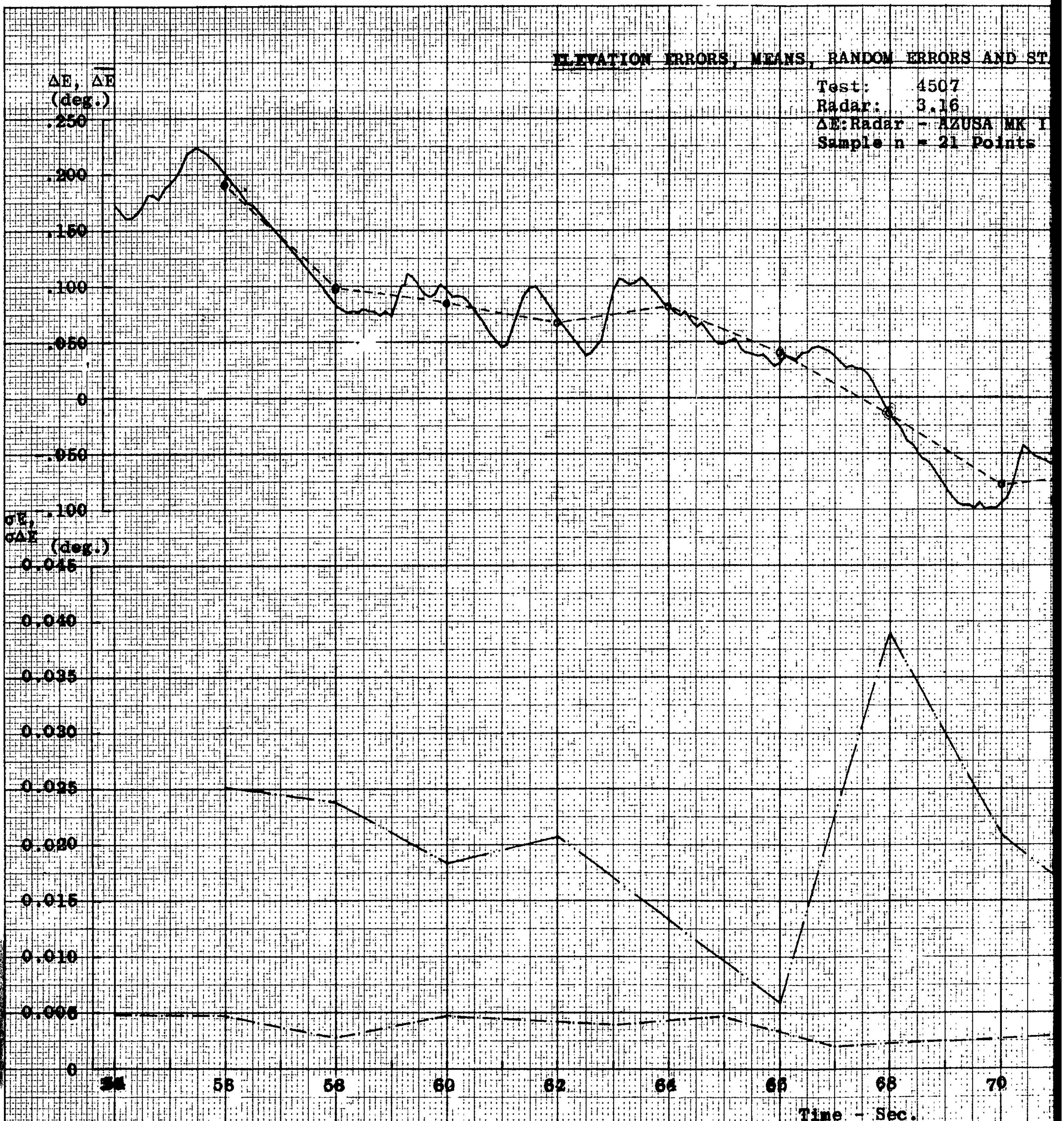
FIG. 8



AZIMUTH ERRORS, MEANS, RANDOM ERRORS AND STAND
Test: 4507
Radar: 3.16
ΔA: Radar - AZUSA MK II
Sample n = 21 Points
ΔA, $\overline{\Delta A}$ (deg)
.020
0
-.020
-.040
-.060
-.080
-.100
-.120
-.140
-.160
σA, σΔA (deg)
.016
.014
.012
.010
.008
.006
.004
.002
0
54
56
58
60
62
64
66
68
70
Time - Sec.

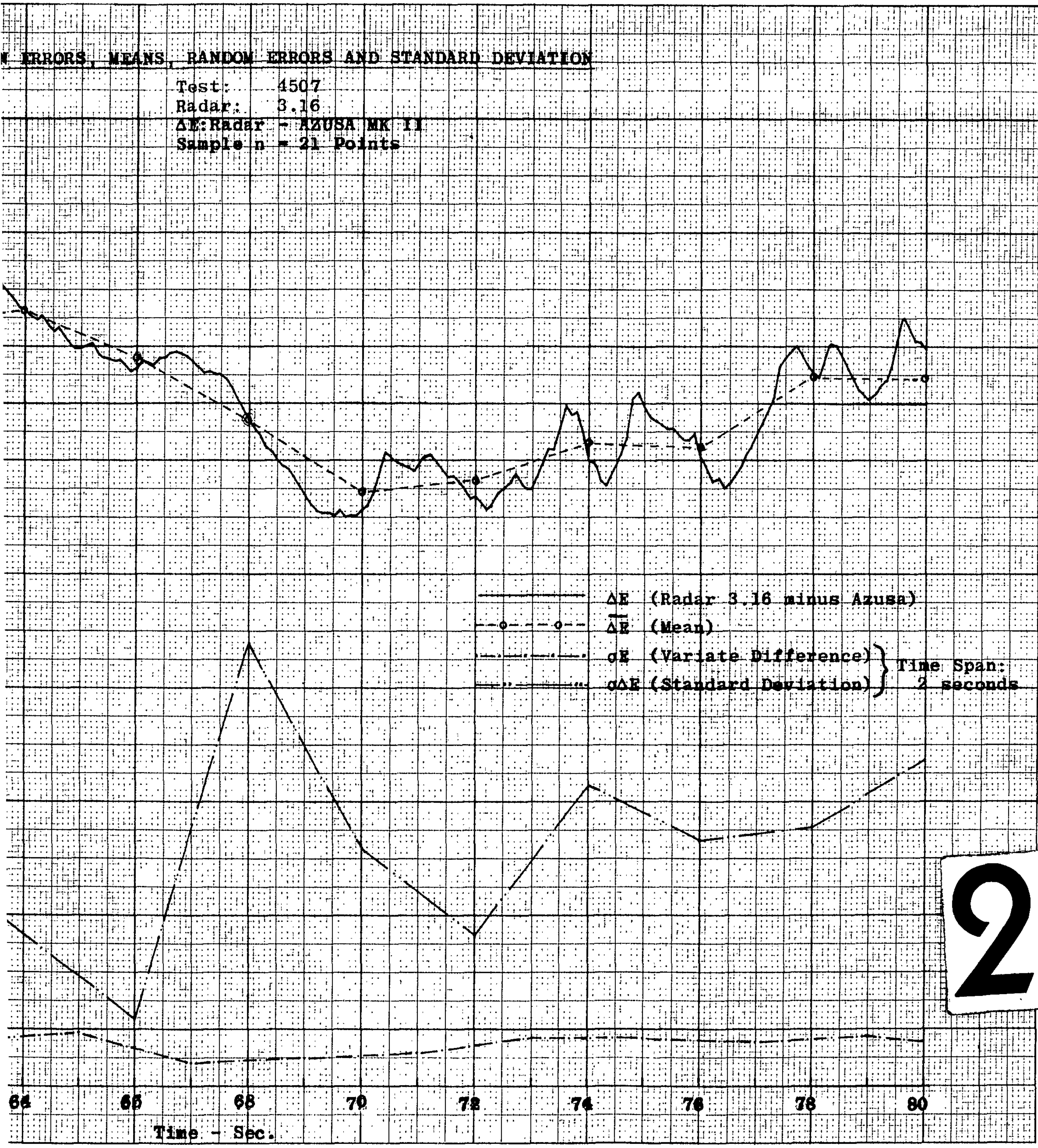
FIG. 9


RRORS, MEANS, RANDOM ERRORS AND STANDARD DEVIATION
Test: 4507
Radar: 3.16
ΔA: Radar - AZUSA MK II
Sample n = 21 Points
ΔA (Radar 3.16 minus Azusa)
$\overline{\Delta A}$ (Mean)
σA (Variate Difference)
σΔA (Standard Deviation)
Time Span: 2 seconds
4
66
68
70
72
74
76
78
80
Time - Sec.
2



ELEVATION ERRORS, MEANS, RANDOM ERRORS AND ST
Test: 4507
Radar: 3.16
ΔE:Radar - AZUSA MK I
Sample n = 21 Points
ΔE, $\overline{\Delta E}$ (deg.)
.250
.200
.150
.100
.050
0
-.050
-.100
σE, σΔE (deg.)
0.045
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0
54
56
58
60
62
64
66
68
70
Time - Sec.

FIG.10



ERRORS, MEANS, RANDOM ERRORS AND STANDARD DEVIATION
Test: 4507
Radar: 3.16
ΔE:Radar - AZUSA MK II
Sample n = 21 Points
ΔE (Radar 3.16 minus Azusa)
$\overline{\Delta E}$ (Mean)
σE (Variate Difference)
σΔE (Standard Deviation)
Time Span: 2 seconds
64
66
68
70
72
74
76
78
80
Time - Sec.

2

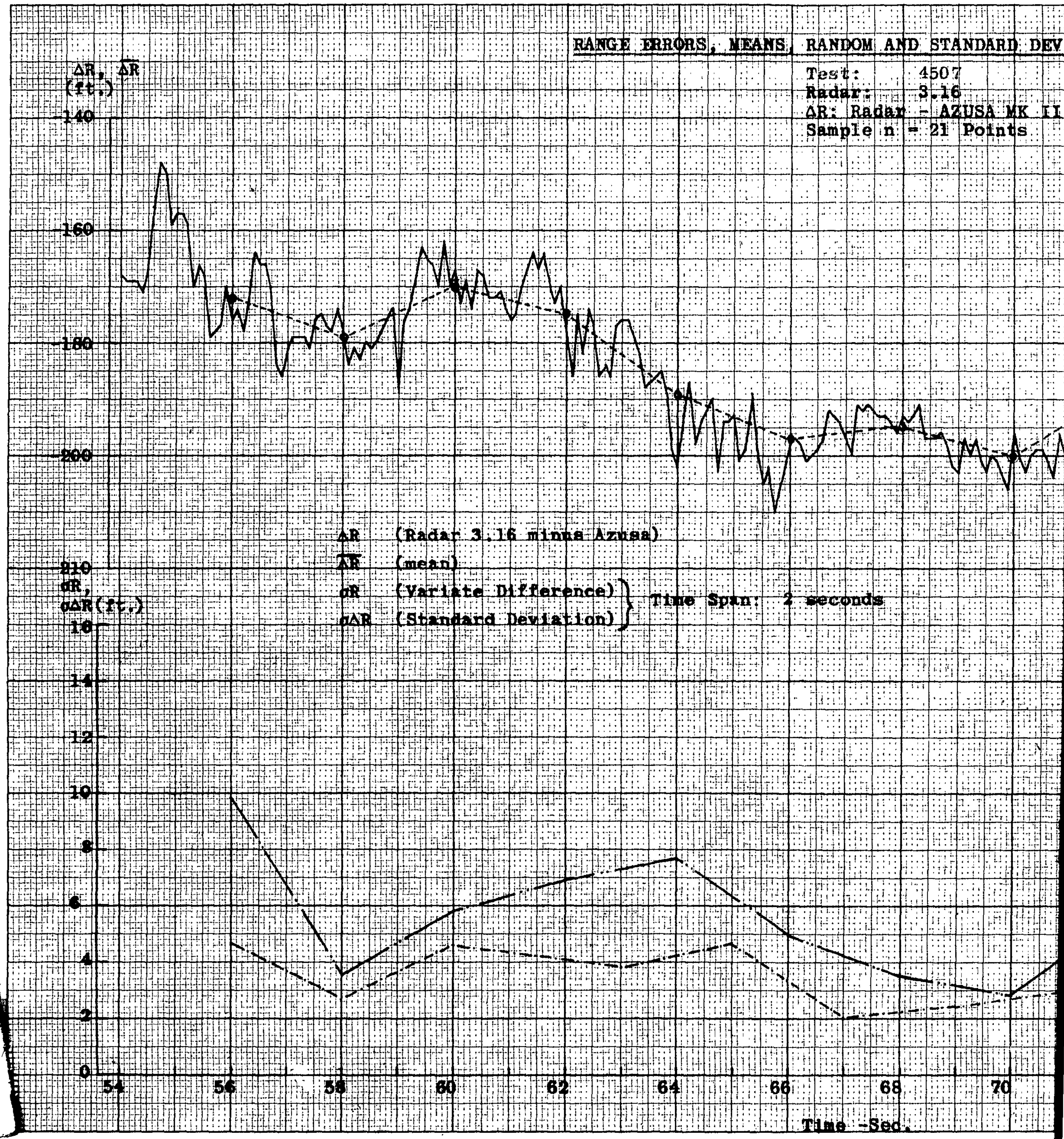
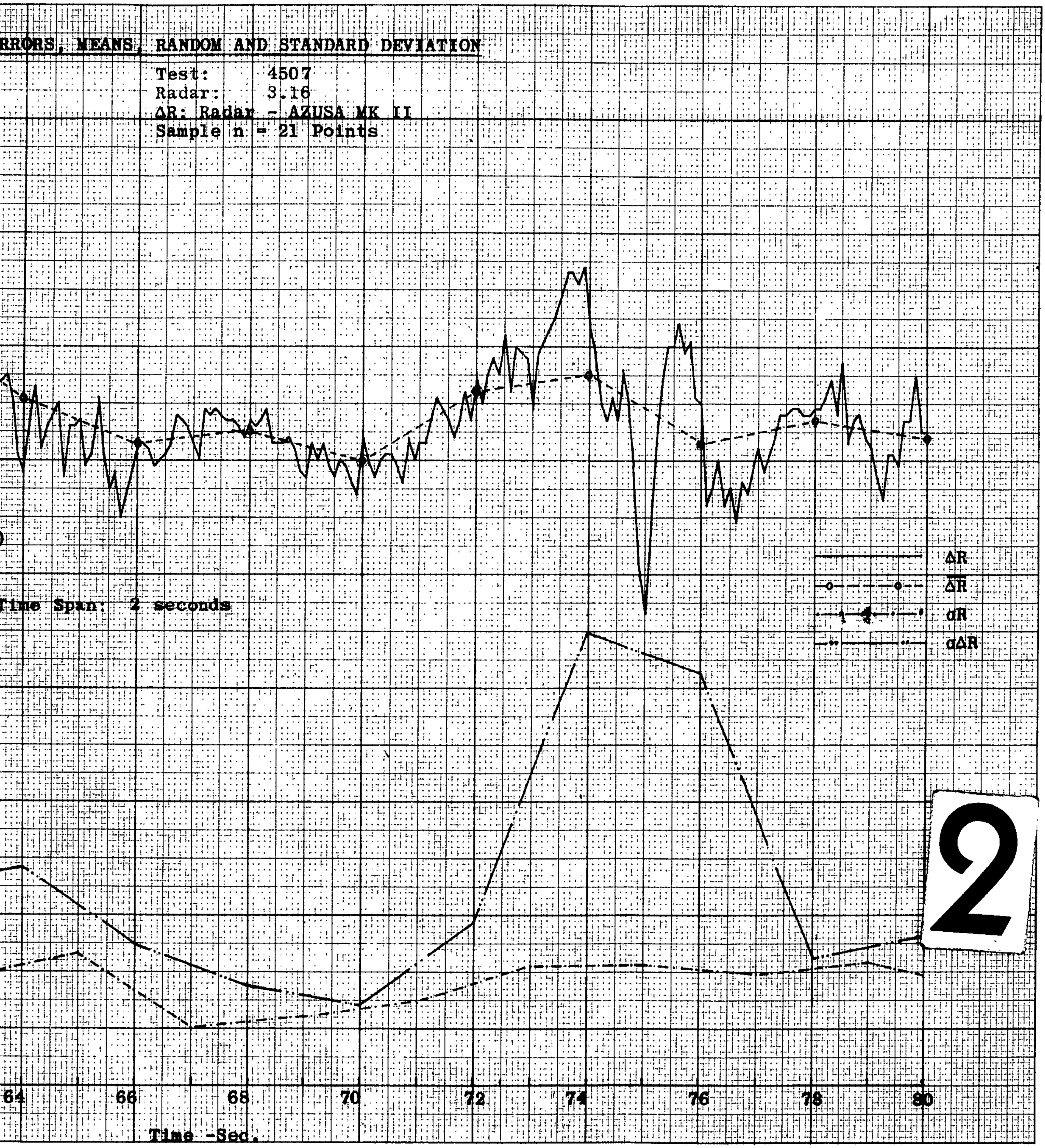

RANGE ERRORS, MEANS, RANDOM AND STANDARD DEVI
Test: 4507
Radar: 3.16
ΔR: Radar - AZUSA MK II
Sample n = 21 Points
ΔR, $\overline{\Delta R}$ (ft.)
140
160
180
200
210
ΔR (Radar 3.16 minus Azusa)
$\overline{\Delta R}$ (mean)
σR (Variate Difference)
σΔR (Standard Deviation)
Time Span: 2 seconds
σR, σΔR (ft.)
16
14
12
10
8
6
4
2
0
54
56
58
60
62
64
66
68
70
Time -Sec.

FIG. 11


RRORS, MEANS, RANDOM AND STANDARD DEVIATION
Test: 4507
Radar: 3.16
ΔR: Radar - AZUSA MK II
Sample n = 21 Points
Time Span: 2 seconds
ΔR
$\overline{\Delta R}$
σR
σΔR
64
66
68
70
72
74
76
78
80
Time -Sec.
2

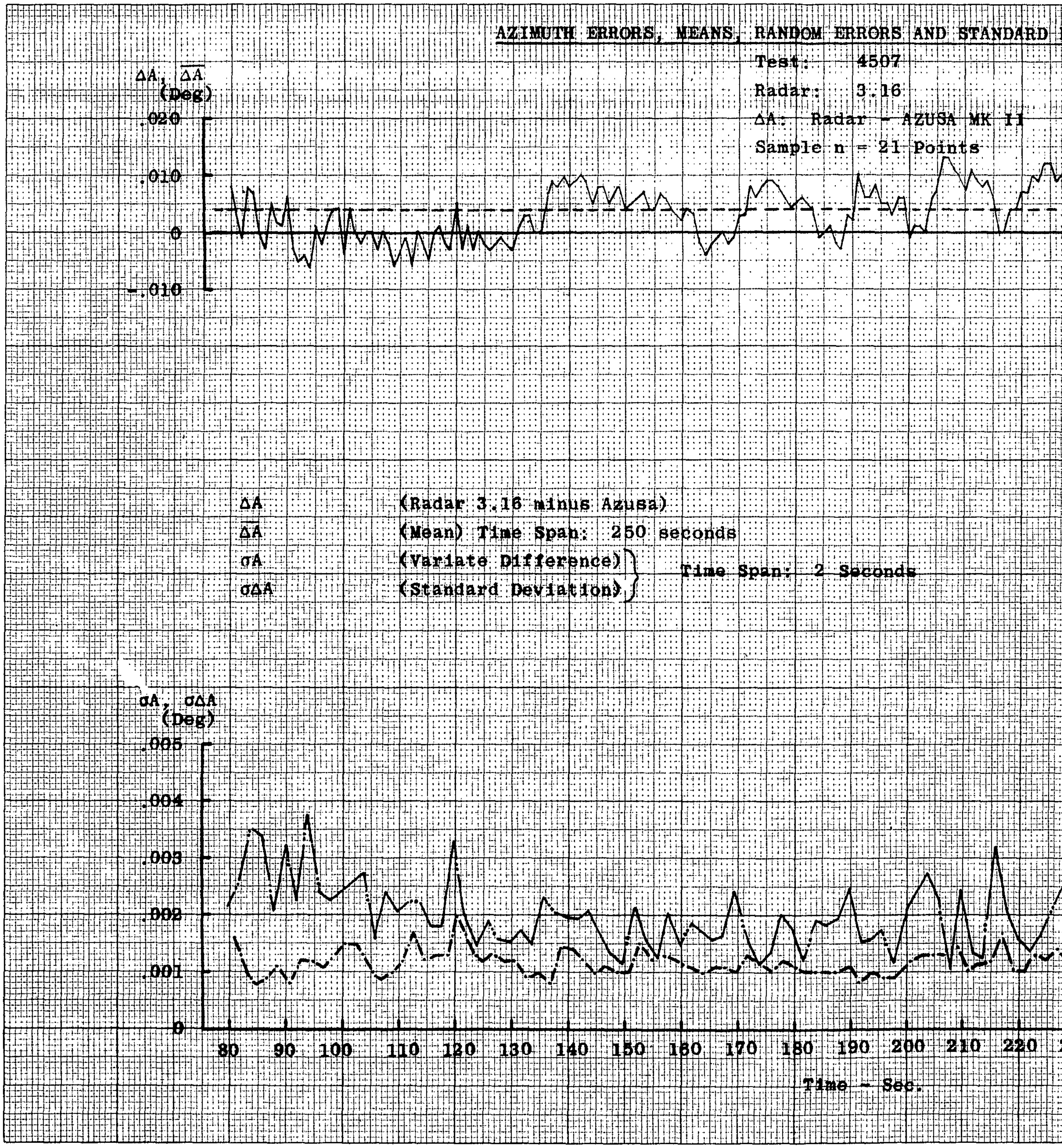
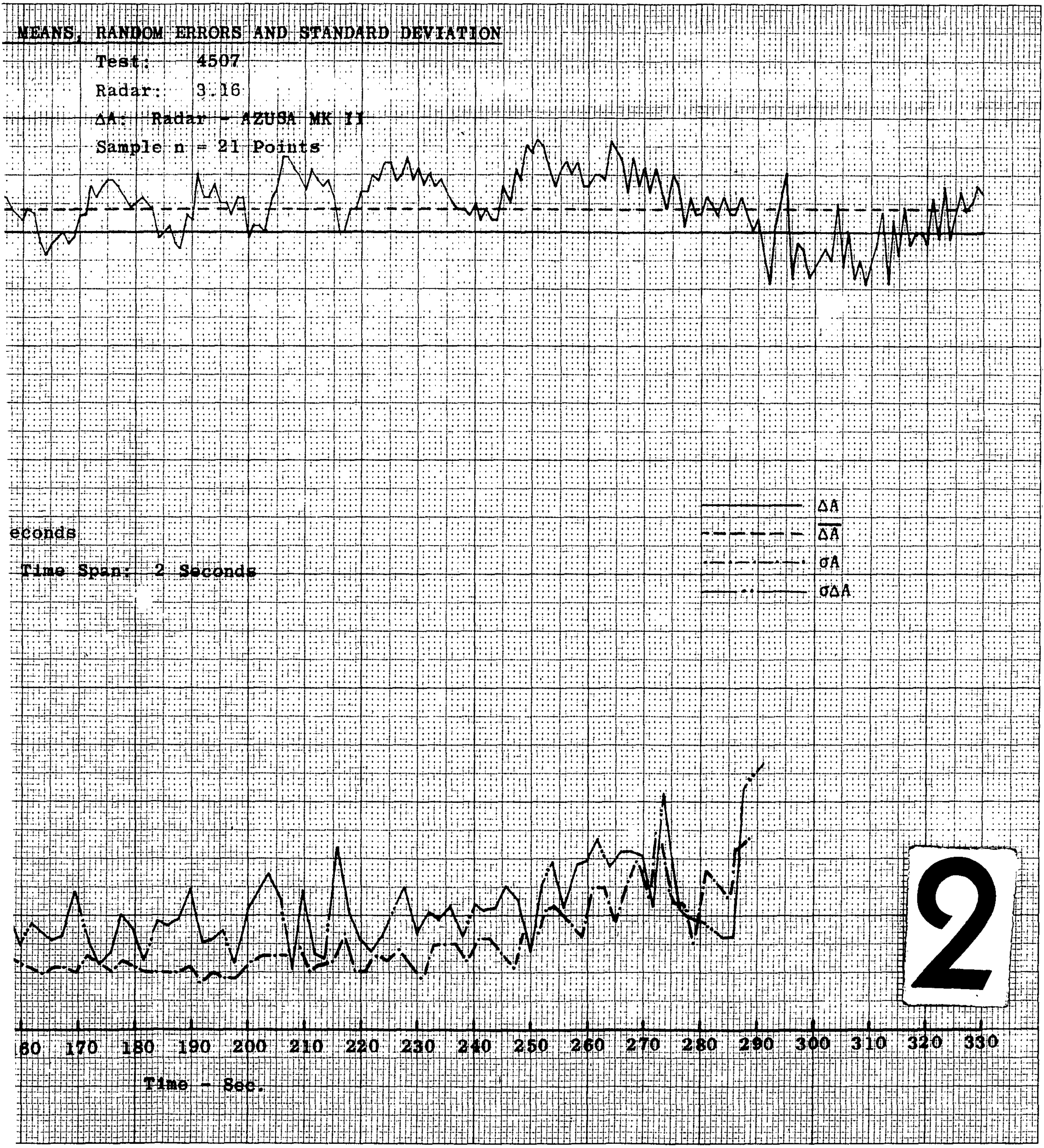
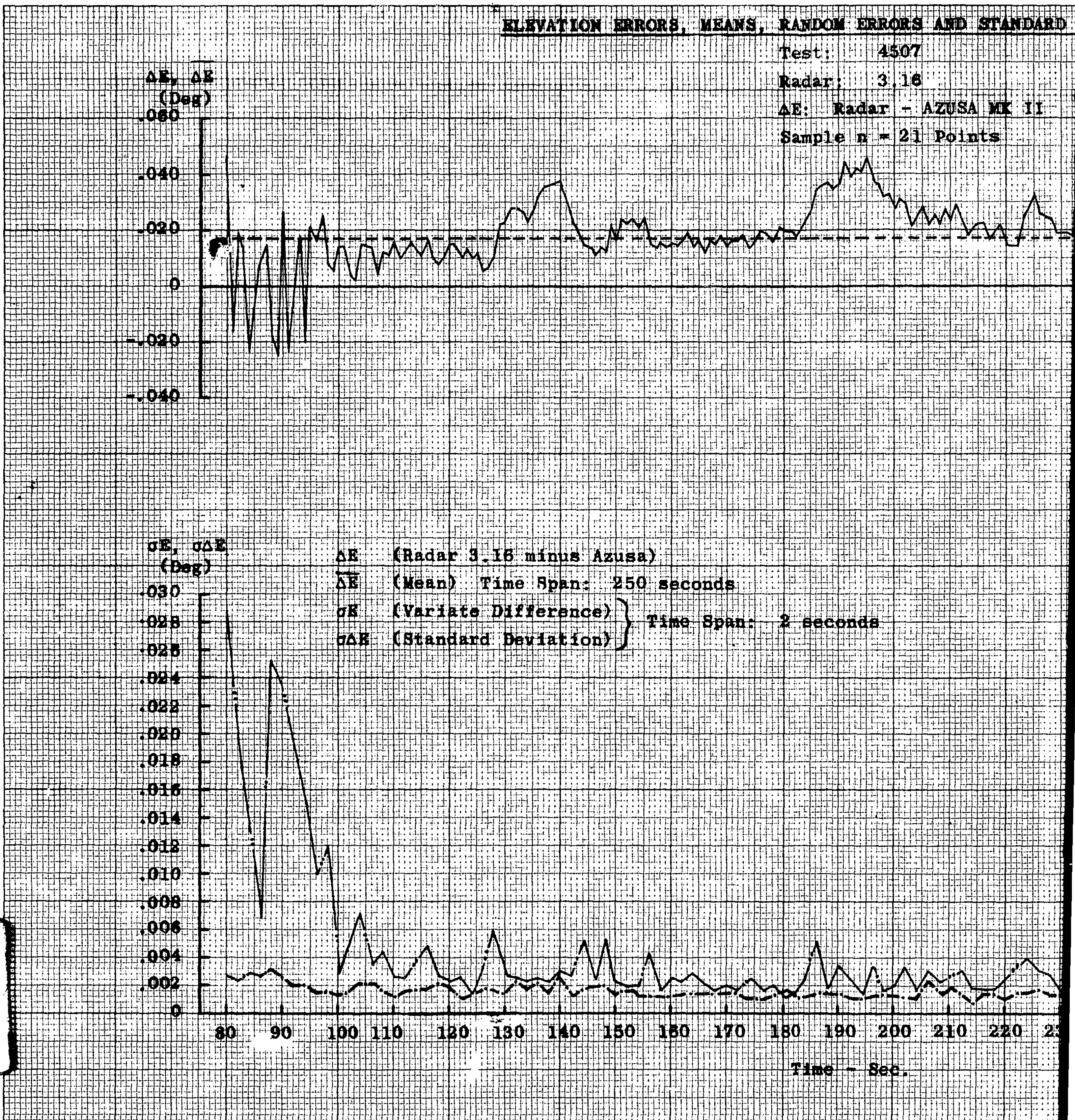
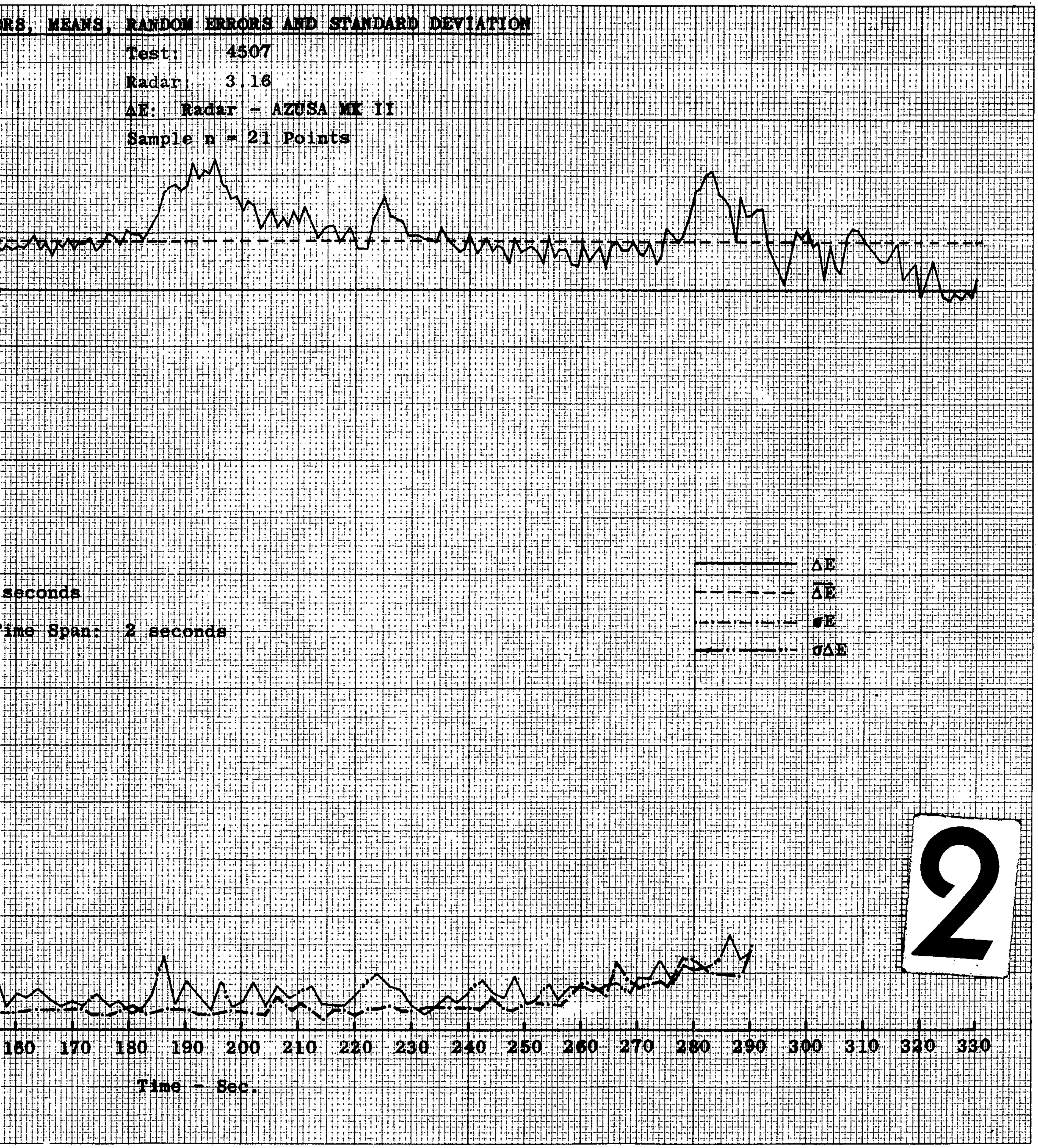

AZIMUTH ERRORS, MEANS, RANDOM ERRORS AND STANDARD D
Test: 4507
Radar: 3.16
ΔA: Radar - AZUSA MK II
Sample n = 21 Points
ΔA, $\overline{\Delta A}$ (Deg)
.020
.010
0
-.010
ΔA (Radar 3.16 minus Azusa)
$\overline{\Delta A}$ (Mean) Time Span: 250 seconds
σA (Variate Difference)
σΔA (Standard Deviation)
Time Span: 2 Seconds
σA, σΔA (Deg)
.005
.004
.003
.002
.001
0
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
Time - Sec.

FIG. 12


MEANS, RANDOM ERRORS AND STANDARD DEVIATION
Test: 4507
Radar: 3.16
ΔA: Radar - AZUSA MK II
Sample n = 21 Points
ΔA
$\overline{\Delta A}$
σA
σΔA
econds
Time Span: 2 Seconds
160 170 180 190 200 210 220 230 240 250 260 270 280 290 300 310 320 330
Time - Sec.
2


ELEVATION ERRORS, MEANS, RANDOM ERRORS AND STANDARD
Test: 4507
Radar: 3.16
ΔE: Radar - AZUSA MK II
Sample n = 21 Points
ΔE, $\overline{\Delta E}$ (Deg)
.060
.040
.020
0
-.020
-.040
σE, σΔE (Deg)
ΔE (Radar 3.16 minus Azusa)
$\overline{\Delta E}$ (Mean) Time Span: 250 seconds
σE (Variate Difference)
σΔE (Standard Deviation)
Time Span: 2 seconds
.030
.028
.026
.024
.022
.020
.018
.016
.014
.012
.010
.008
.006
.004
.002
0
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
Time - Sec.



ORS, MEANS, RANDOM ERRORS AND STANDARD DEVIATION
Test: 4507
Radar: 3.16
ΔE: Radar - AZUSA MK II
Sample n = 21 Points
seconds
Time Span: 2 seconds
ΔE
ΔE
σE
σΔE
160 170 180 190 200 210 220 230 240 250 260 270 280 290 300 310 320 330
Time - Sec.
2

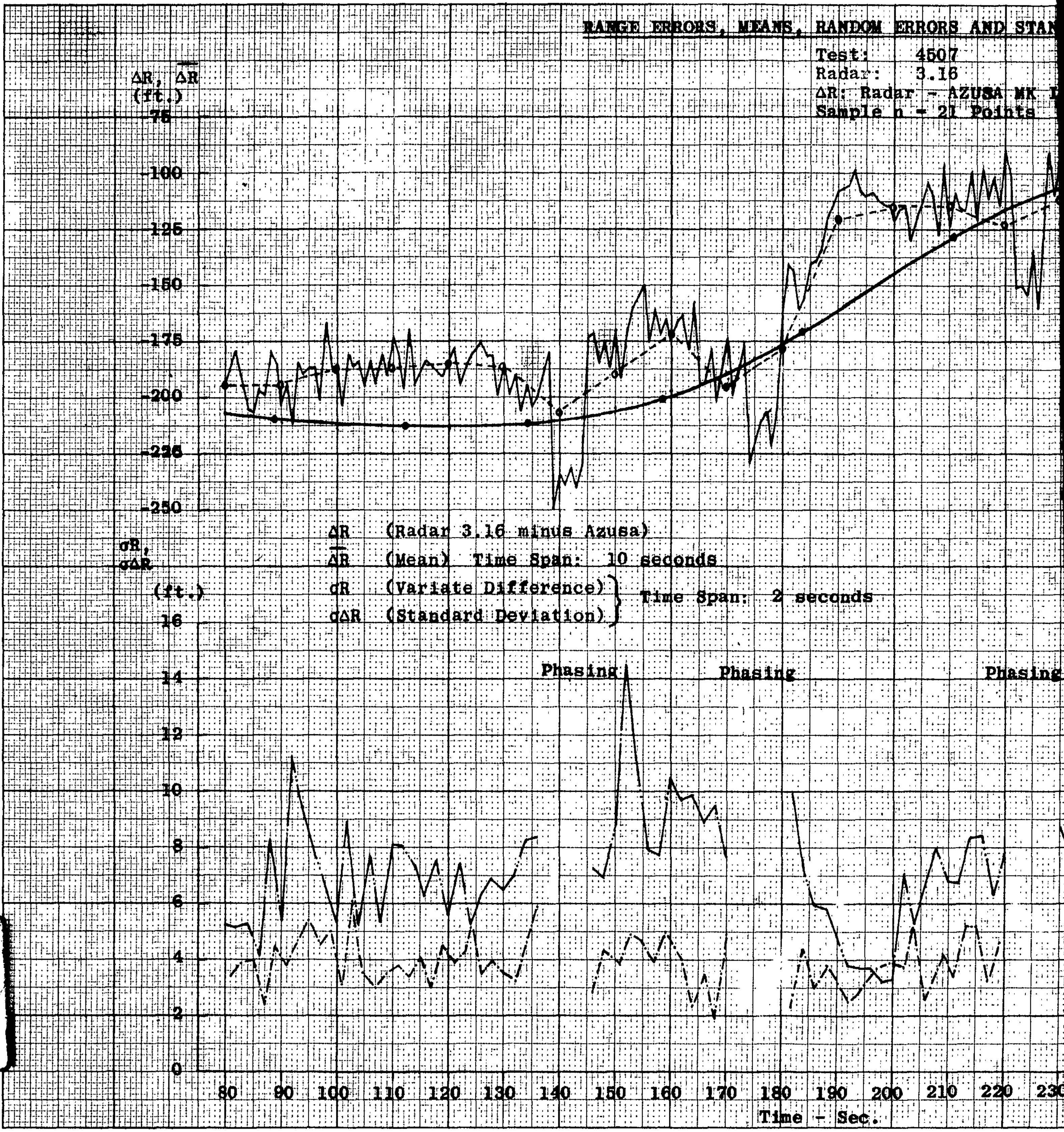
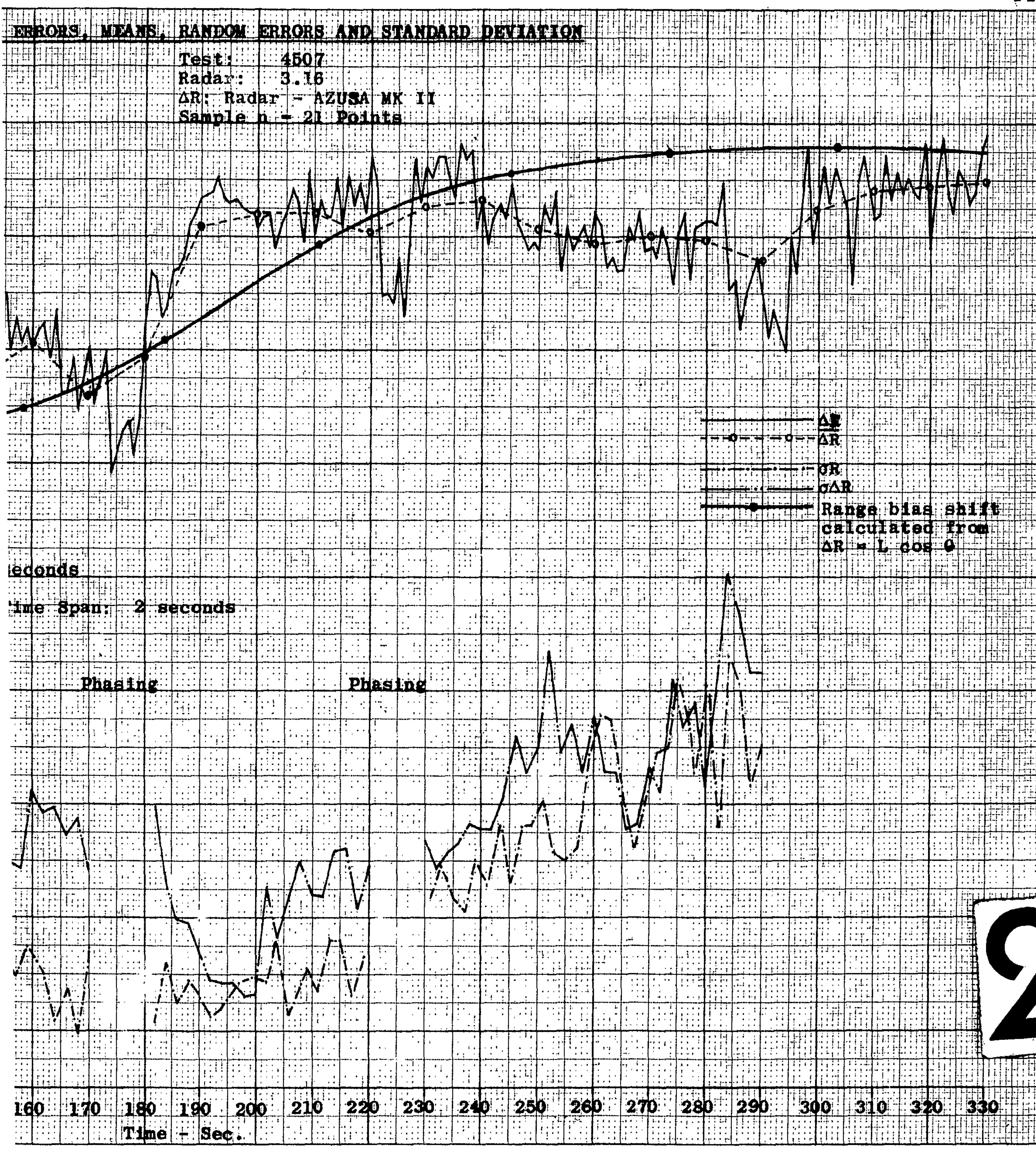
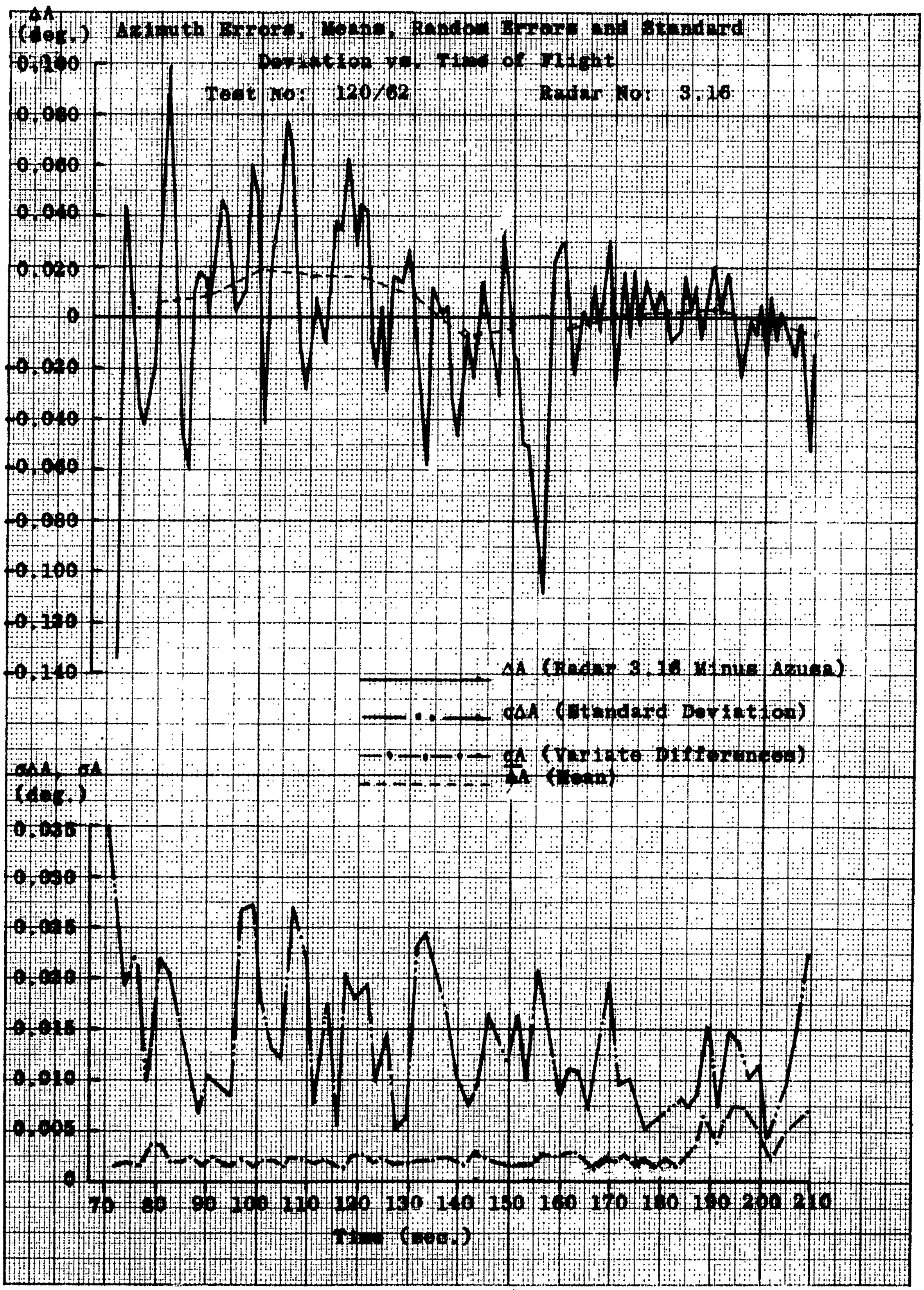

RANGE ERRORS, MEANS, RANDOM ERRORS AND STAN
Test: 4507
Radar: 3.16
ΔR: Radar - AZUSA MK I
Sample n = 21 Points
ΔR, $\overline{\Delta R}$ (ft.)
-75
-100
-125
-150
-175
-200
-225
-250
ΔR (Radar 3.16 minus Azusa)
$\overline{\Delta R}$ (Mean) Time Span: 10 seconds
σR (Variate Difference)
σΔR (Standard Deviation)
Time Span: 2 seconds
σR, σΔR (ft.)
16
14
12
10
8
6
4
2
0
Phasing
Phasing
Phasing
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
Time - Sec.

FIG. 14



ERRORS, MEANS, RANDOM ERRORS AND STANDARD DEVIATION
Test: 4507
Radar: 3.16
ΔR: Radar - AZUSA MK II
Sample n = 21 Points
ΔR
ΔR
σR
σΔR
Range bias shift calculated from ΔR = L cos θ
econds
ime Span: 2 seconds
Phasing
Phasing
160 170 180 190 200 210 220 230 240 250 260 270 280 290 300 310 320 330
Time - Sec.

FIG.15



ΔA (deg.)
Azimuth Errors, Means, Random Errors and Standard Deviation vs. Time of Flight
Test No: 120/62
Radar No: 3.16
0.100
0.080
0.060
0.040
0.020
0
-0.020
-0.040
-0.060
-0.080
-0.100
-0.120
-0.140
ΔA (Radar 3.16 Minus Azusa)
σΔA (Standard Deviation)
σA (Variate Differences)
$\overline{\Delta A}$ (Mean)
σΔA, σA (deg.)
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
Time (sec.)

FIG. 10

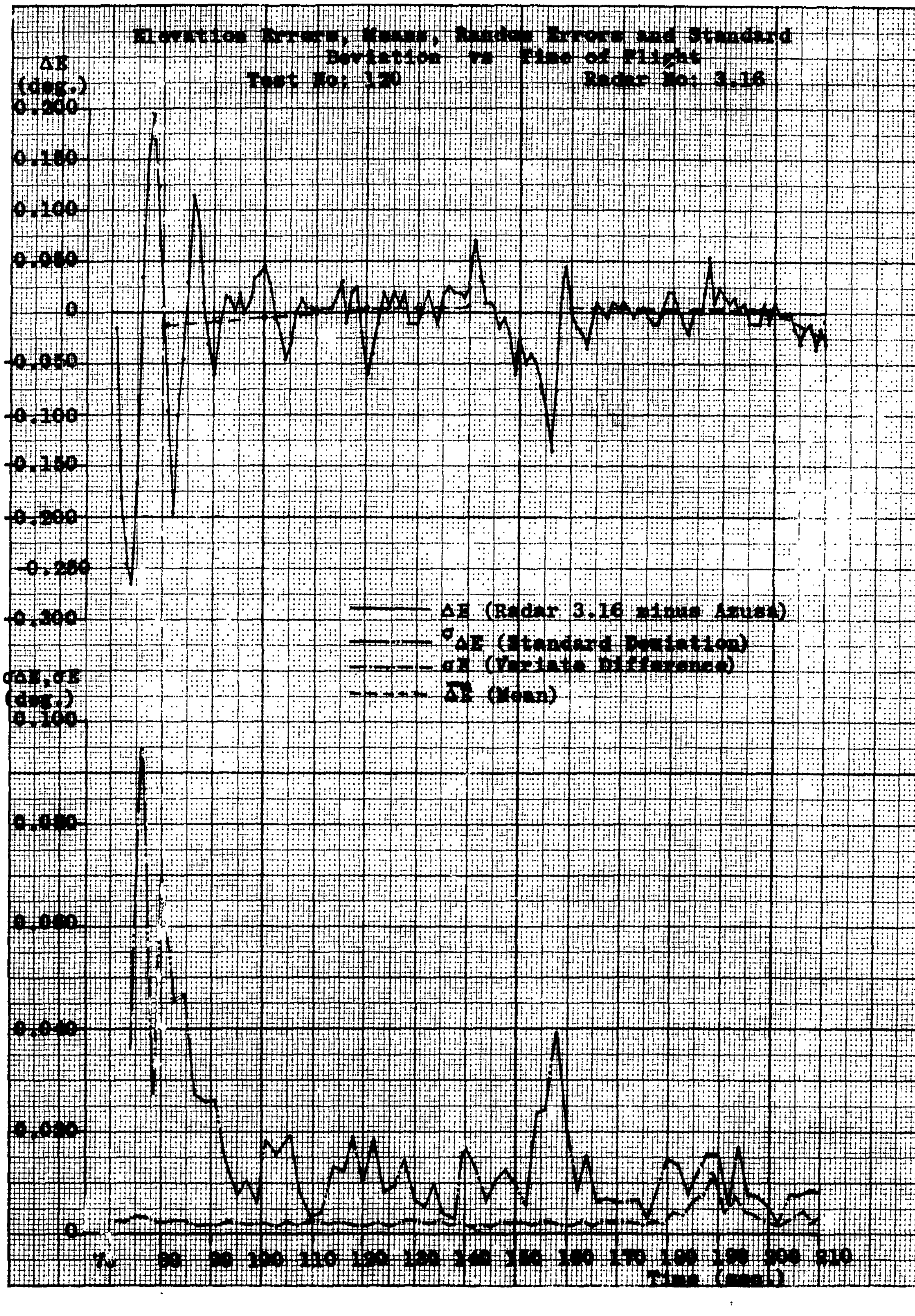
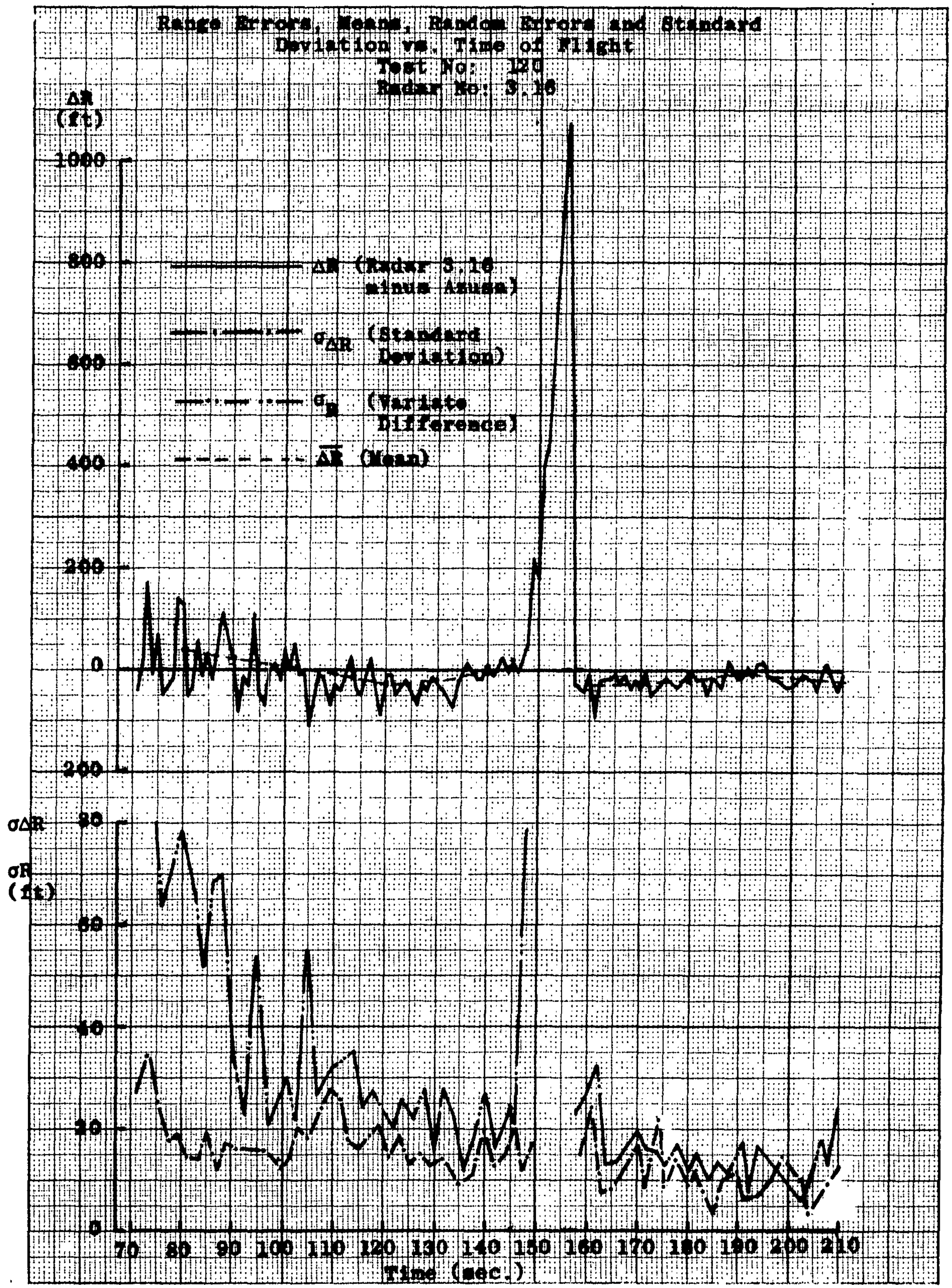

Elevation Errors, Means, Random Errors and Standard Deviation vs Time of Flight
Radar No: 3.16
ΔE (deg.)
0.200
0.150
0.100
0.050
0
-0.050
-0.100
-0.150
-0.200
-0.250
-0.300
ΔE (Radar 3.16 minus Azusa)
σΔE (Standard Deviation)
σE (Variate Difference)
ΔE (Mean)
σΔE, σE (deg.)
0.100
0.080
0.060
0.040
0.020
0
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
Time (sec.)

FIG. 17


Range Errors, Means, Random Errors and Standard Deviation vs. Time of Flight
Test No: 120
Radar No: 3.16
ΔR (ft)
1000
800
600
400
200
0
-200
ΔR (Radar 3.16 minus Azusa)
σΔR (Standard Deviation)
σR (Variate Difference)
ΔR̄ (Mean)
σΔR
σR (ft)
80
60
40
20
0
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
Time (sec.)

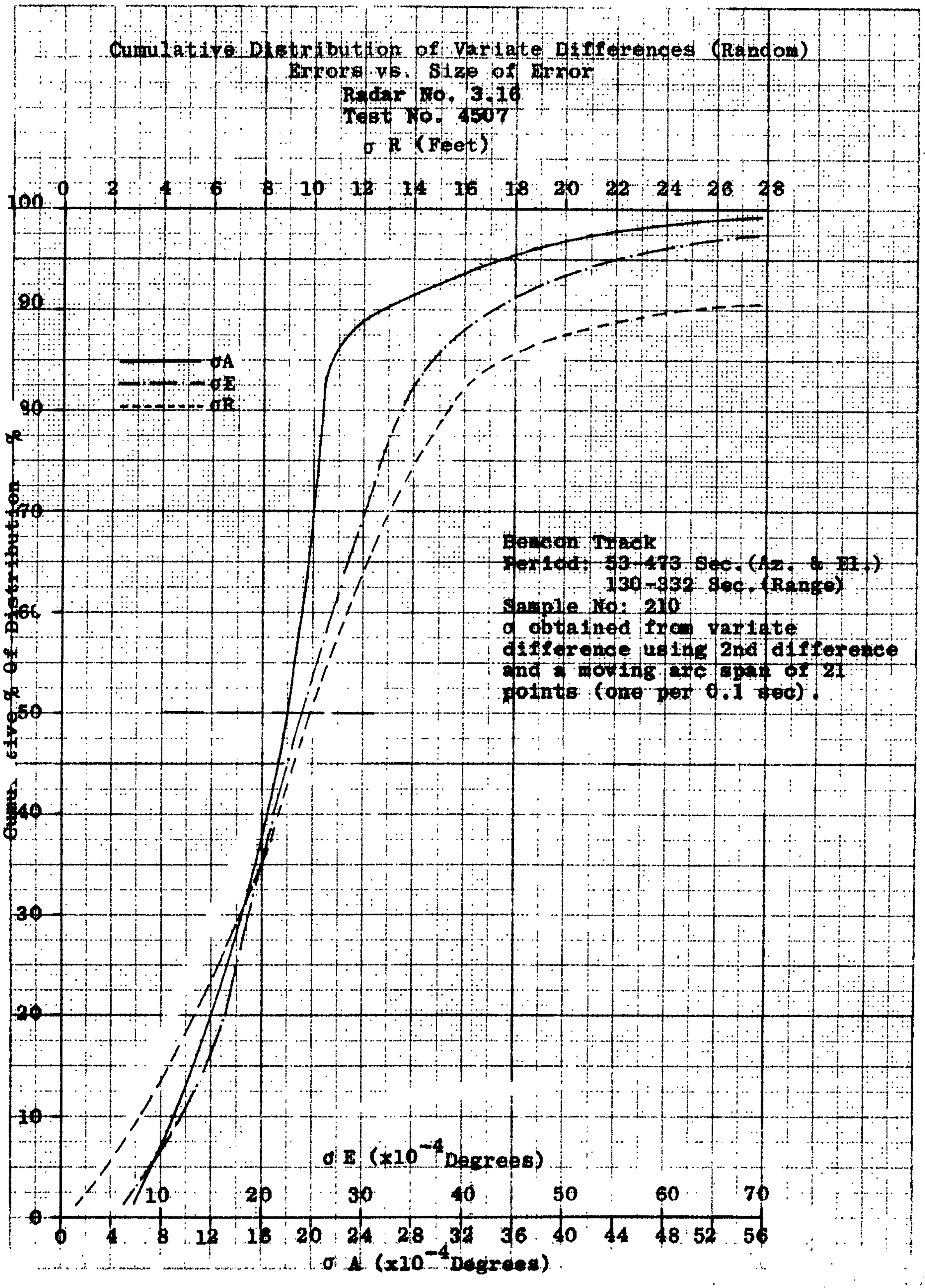
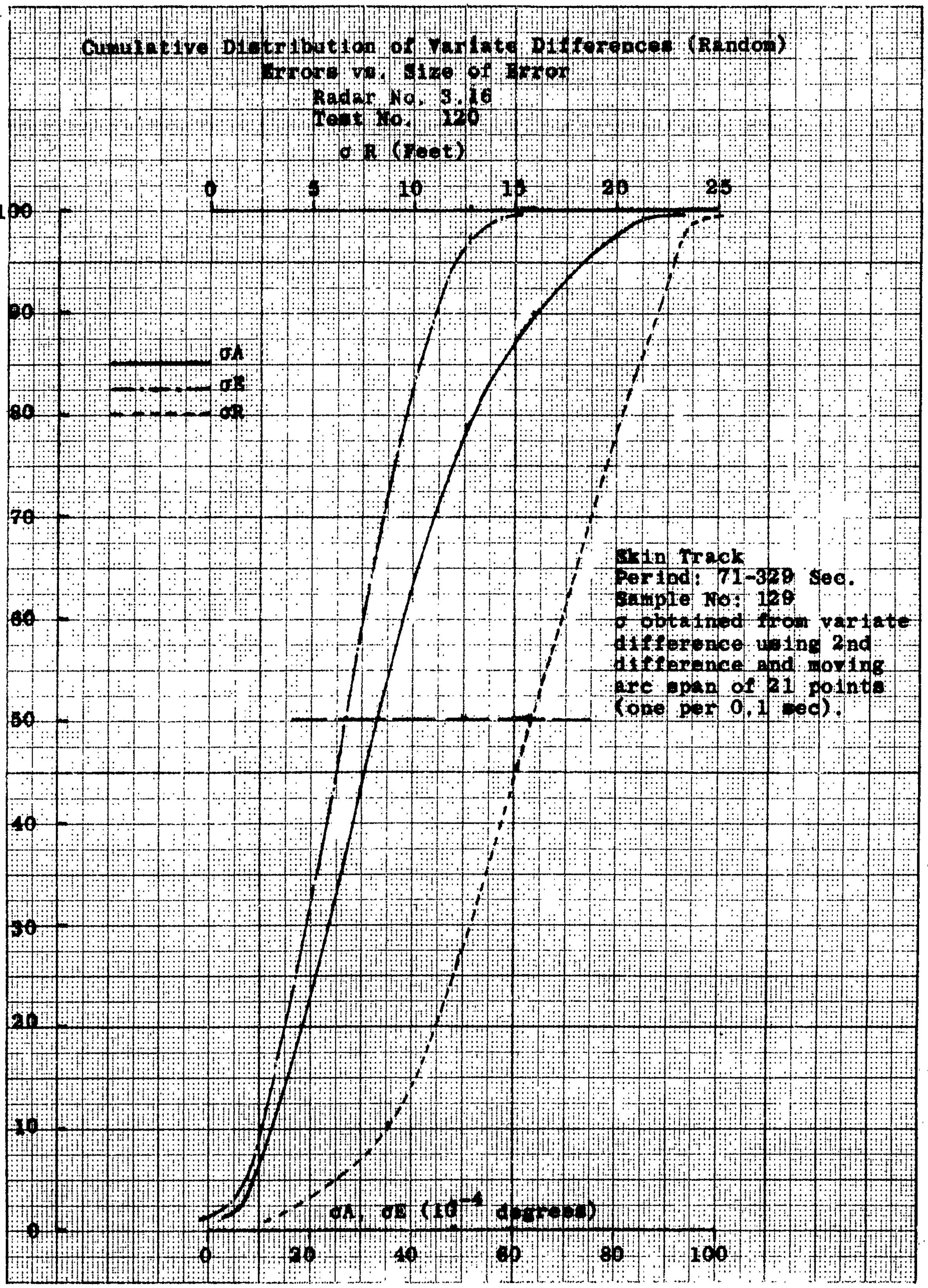
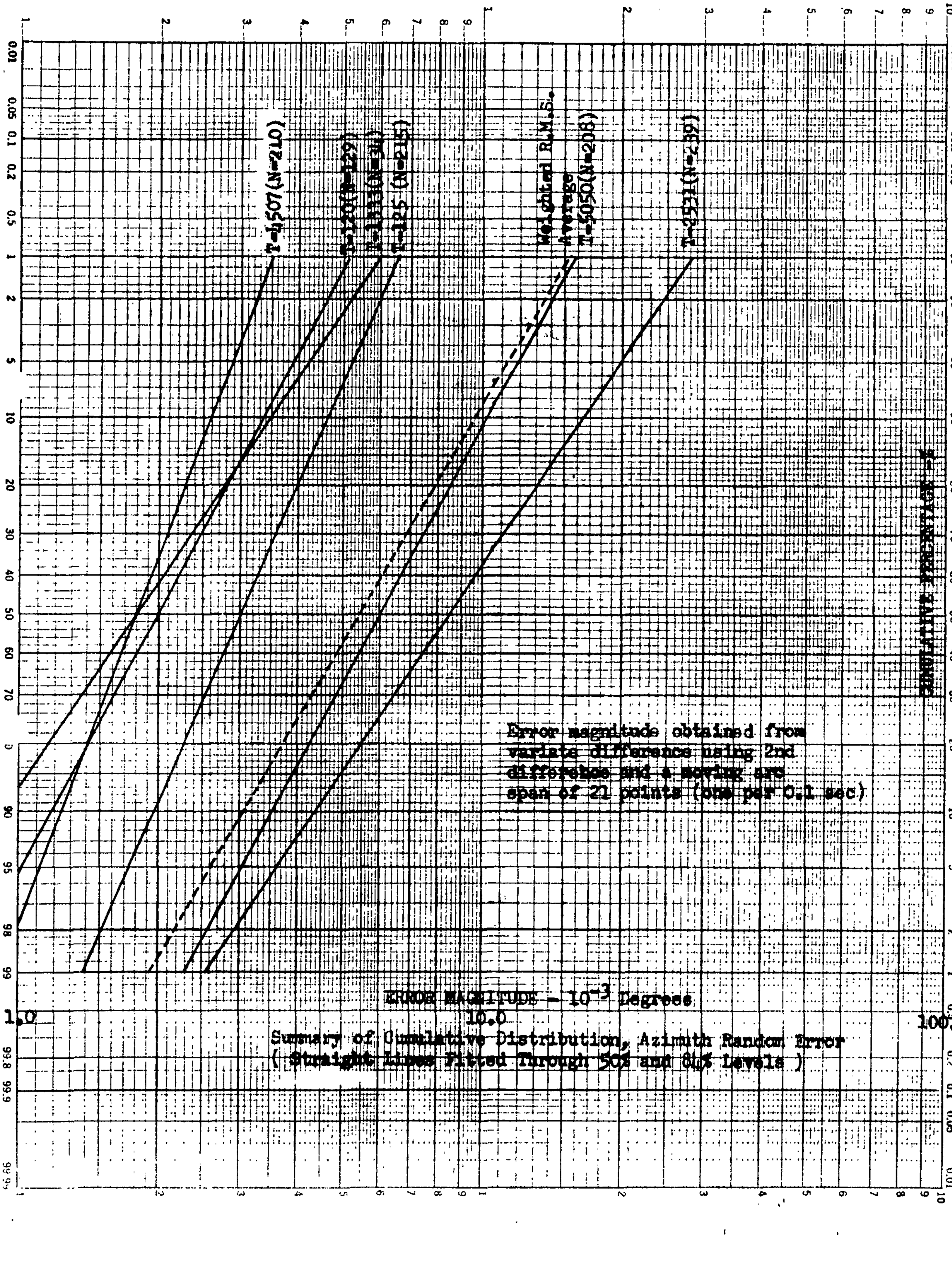

Cumulative Distribution of Variate Differences (Random)
Errors vs. Size of Error
Radar No. 3.16
Test No. 4507
σ R (Feet)
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28
100 90 80 70 60 50 40 30 20 10 0
σA
σE
σR
Cumu. ive % of Distribution %
Beacon Track
Period: 53-473 Sec. (Az. & El.)
130-332 Sec. (Range)
Sample No: 210
σ obtained from variate
difference using 2nd difference
and a moving arc span of 21
points (one per 0.1 sec).
σ E (x10^-4 Degrees)
10 20 30 40 50 60 70
0 4 8 12 16 20 24 28 32 36 40 44 48 52 56
σ A (x10^-4 Degrees)

FIG.19



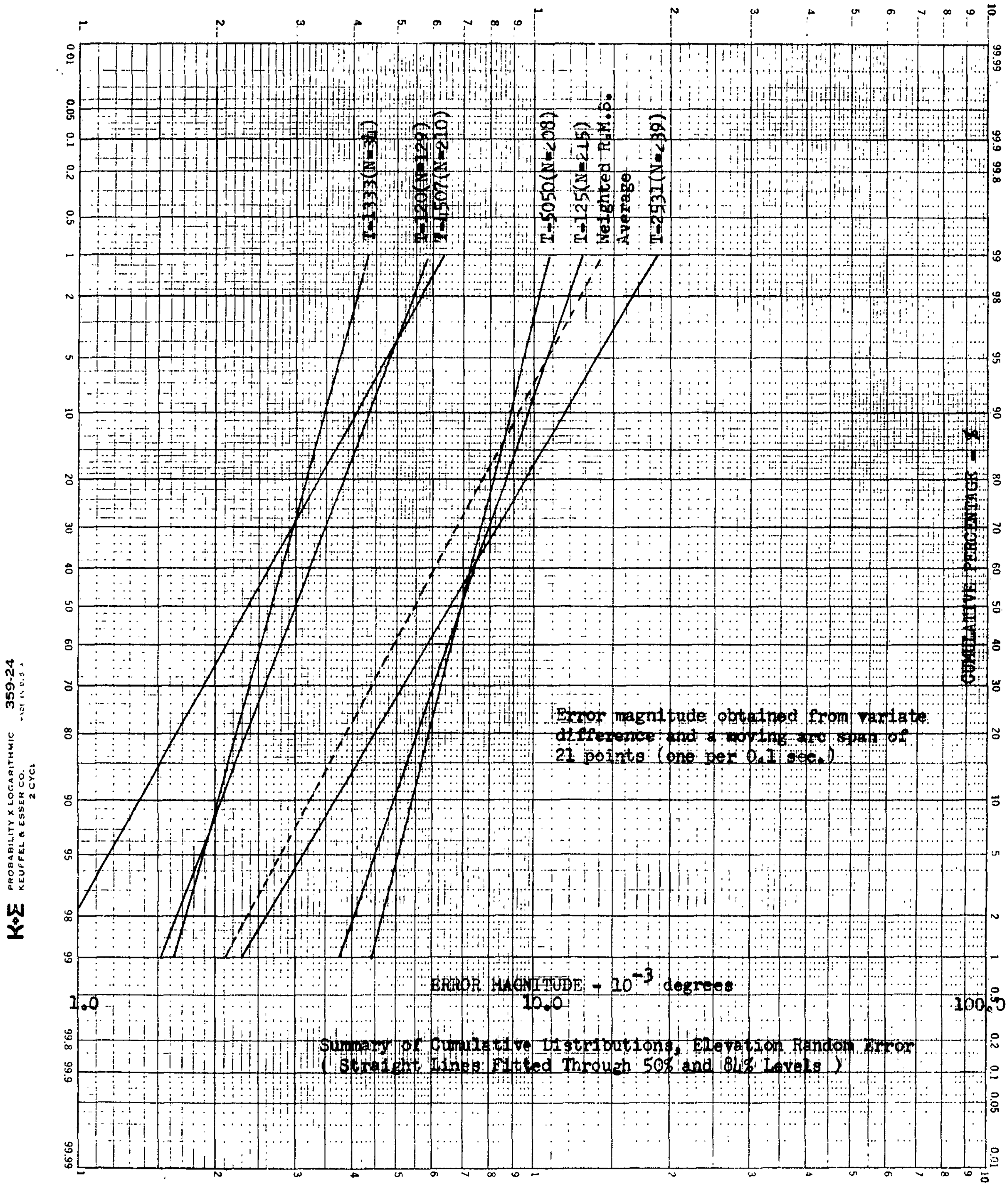
Cumulative Distribution of Variate Differences (Random)
Errors vs. Size of Error
Radar No. 3.16
Test No. 120
σ R (Feet)
0
5
10
15
20
25
100
90
80
70
60
50
40
30
20
10
0
Cumulative % of Distribution
σA
σE
σR
Skin Track
Period: 71-329 Sec.
Sample No: 129
σ obtained from variate difference using 2nd difference and moving arc span of 21 points (one per 0.1 sec).
σA, σE (10^-4 degrees)
0
20
40
60
80
100

FIG. 20



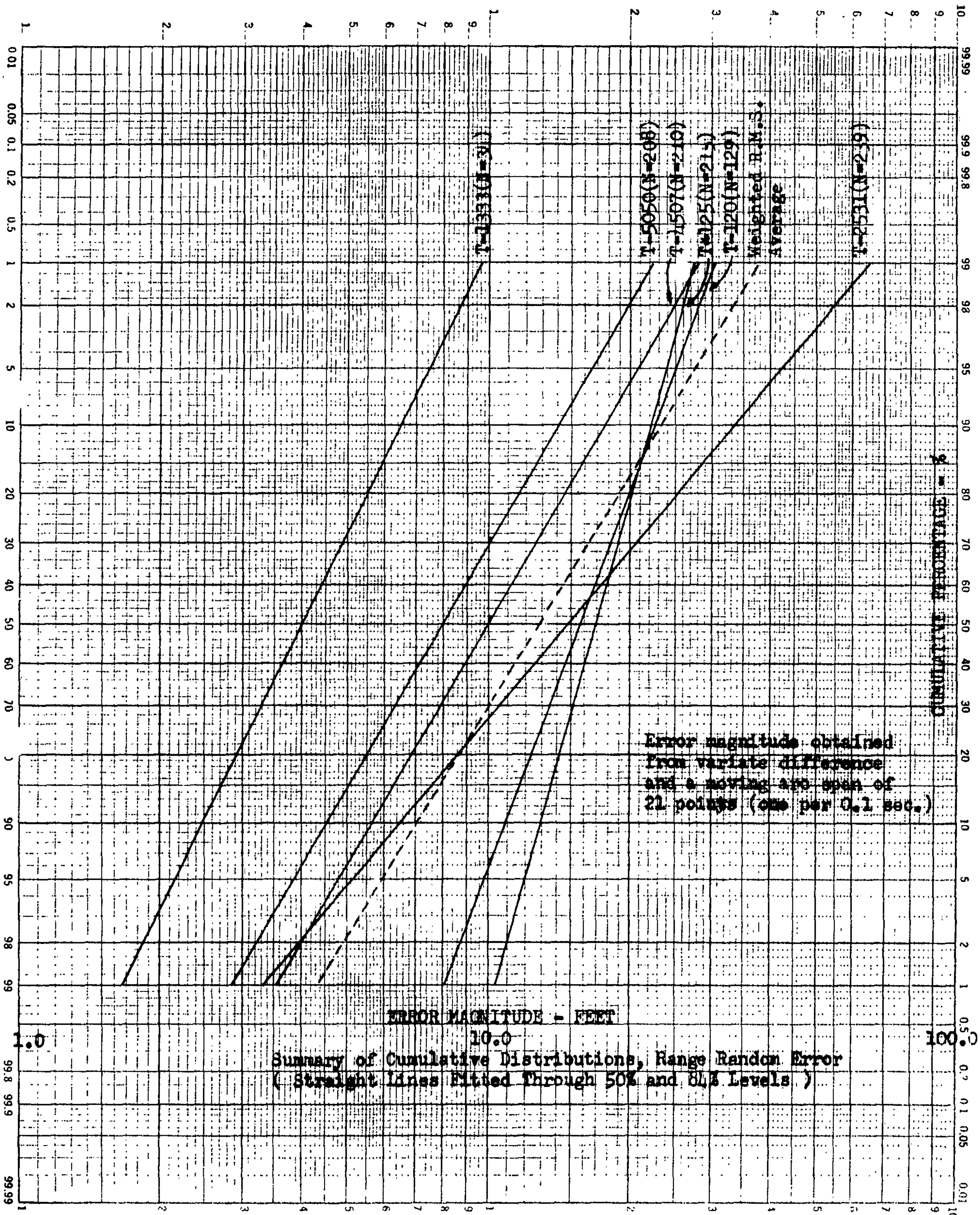
Summary of Cumulative Distribution, Azimuth Random Error
(Straight Lines Fitted Through 50% and 84% Levels)

2



Summary of Cumulative Distributions, Elevation Random Error
(Straight Lines Fitted Through 50% and 84% Levels)

FIG. 22



Summary of Cumulative Distributions, Range Random Error
(Straight Lines Fitted Through 50% and 84% Levels)

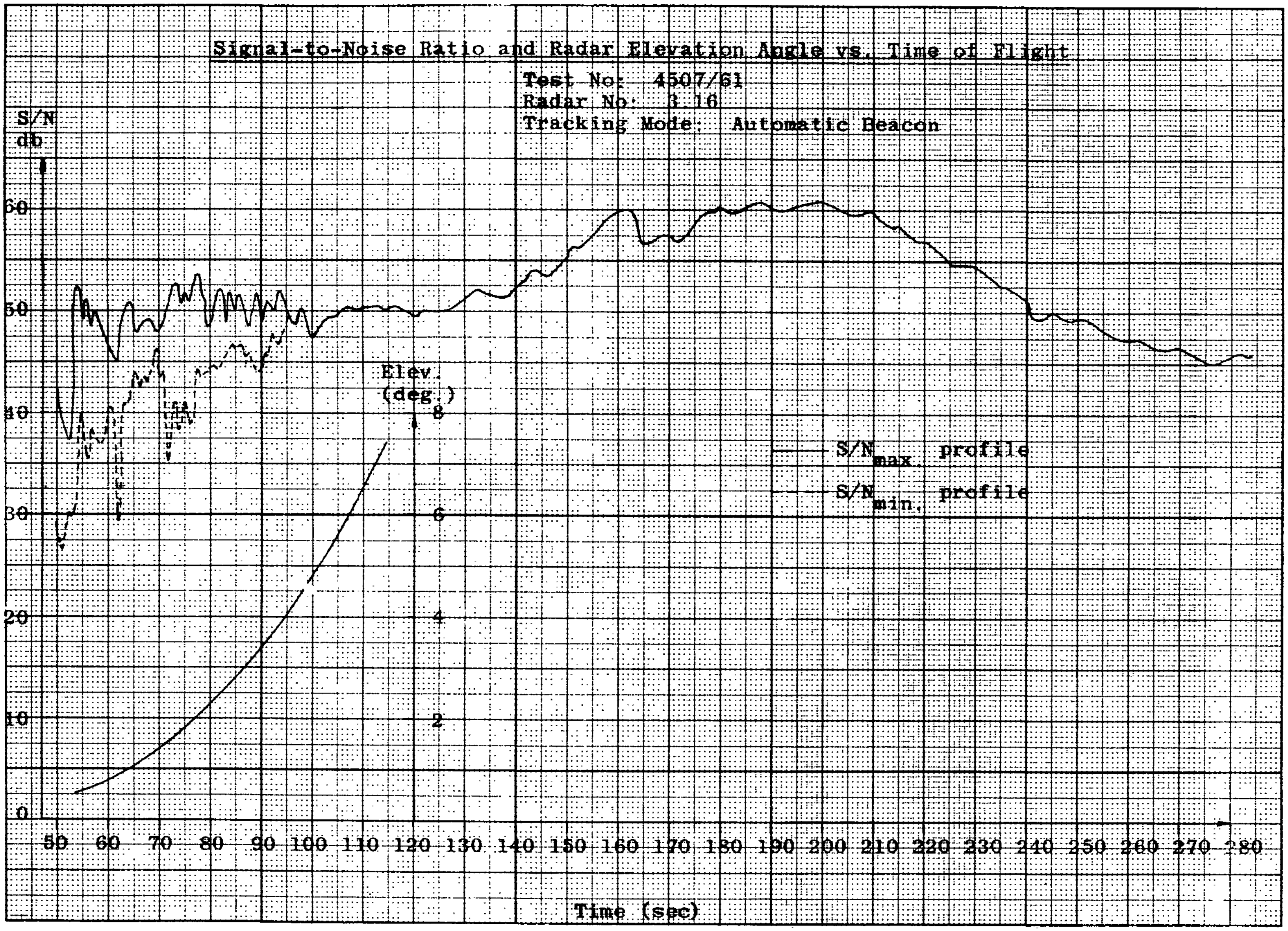
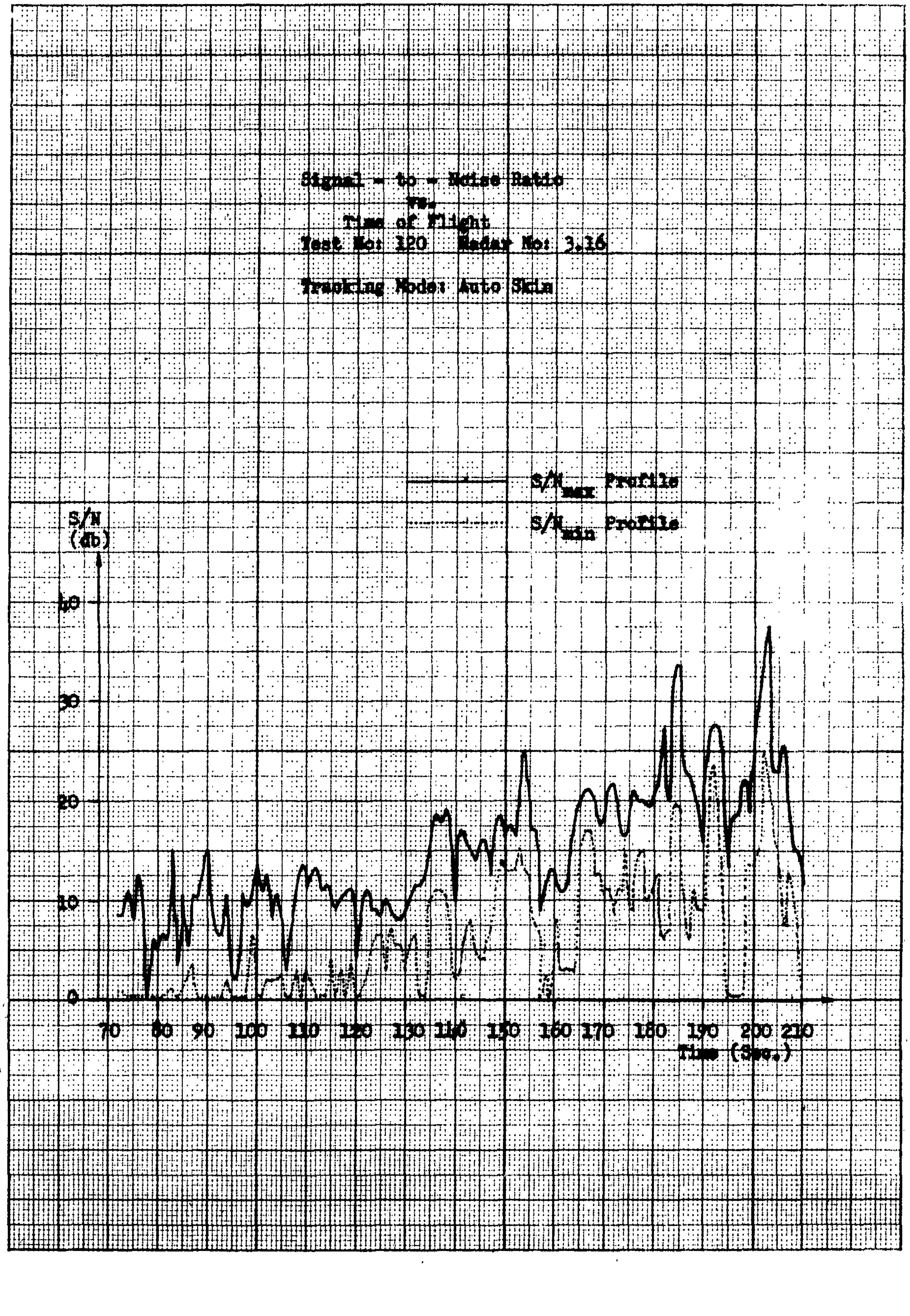

Signal-to-Noise Ratio and Radar Elevation Angle vs. Time of Flight
Test No: 4507/61
Radar No: 3.16
Tracking Mode: Automatic Beacon
S/N
db
60
50
40
30
20
10
0
Elev.
(deg.)
8
6
4
2
S/N max. profile
S/N min. profile
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240
250
260
270
280
Time (sec)

FIG. 23.

FIG. 24



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PRINTED IN U. S. A.
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MILLIMETER

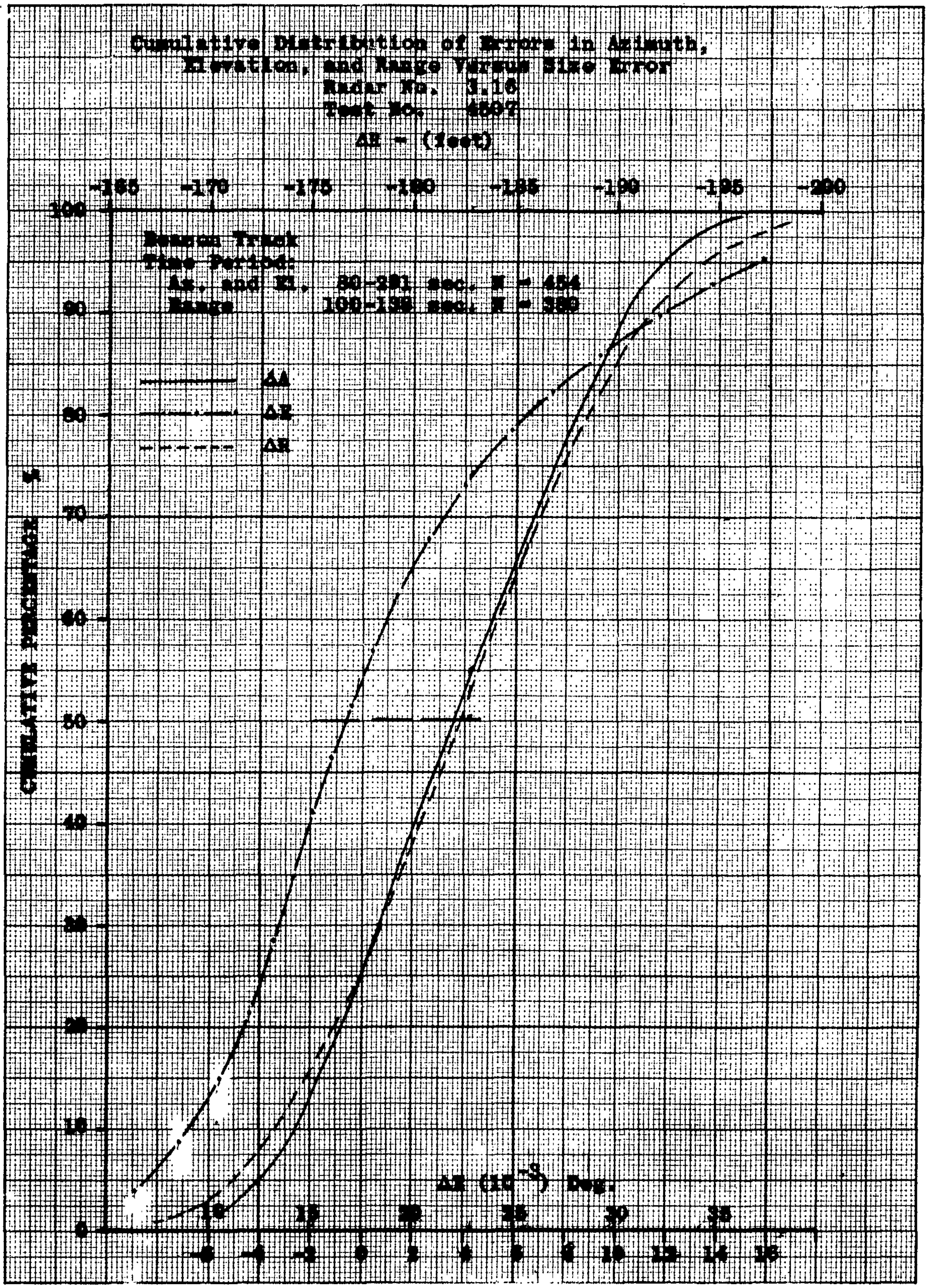
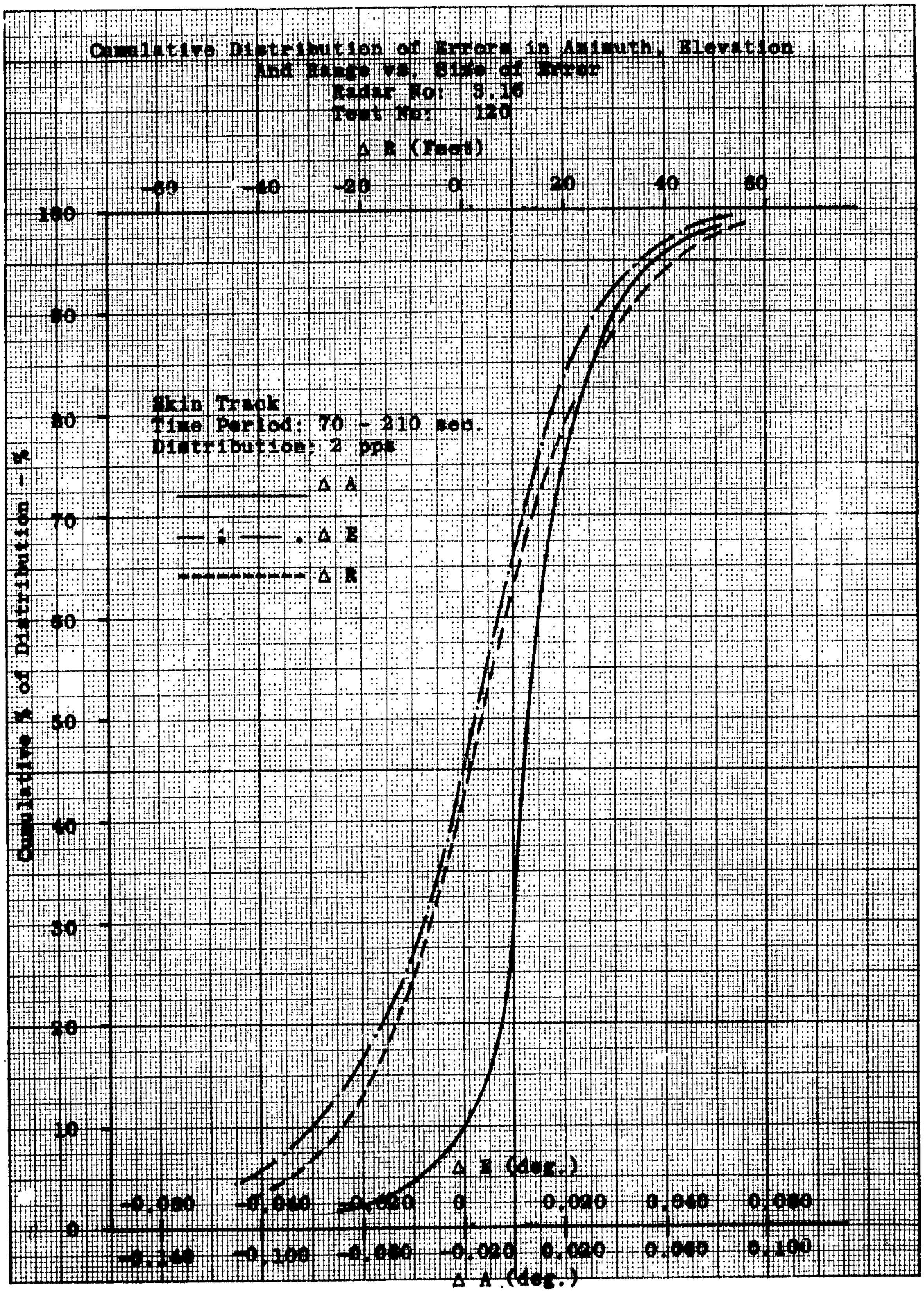

Cumulative Distribution of Errors in Azimuth,
Elevation, and Range Versus Size Error
Radar No. 3.16
Test No. 4597
ΔR - (feet)
-165 -170 -175 -180 -185 -190 -195 -200
Beacon Track
Time Period:
Az. and El. 80-281 sec. N = 454
Range 100-139 sec. N = 389
ΔA
ΔE
ΔR
CUMULATIVE PERCENTAGE %
100 90 80 70 60 50 40 30 20 10 0
ΔA (10^-3) Deg.
10 15 20 25 30 35
-6 -4 -2 0 2 4 6 8 10 12 14 16

FIG.26


Cumulative Distribution of Errors in Azimuth, Elevation
And Range vs. Size of Error
Radar No: 3.16
Test No: 120
Δ R (Feet)
-60 -40 -20 0 20 40 60
100 90 80 70 60 50 40 30 20 10 0
Cumulative % of Distribution - %
Skin Track
Time Period: 70 - 210 sec.
Distribution: 2 pps
Δ A
Δ E
Δ R
Δ E (deg.)
-0.060 -0.040 -0.020 0 0.020 0.040 0.060
-0.140 -0.100 -0.060 -0.020 0.020 0.060 0.100
Δ A (deg.)

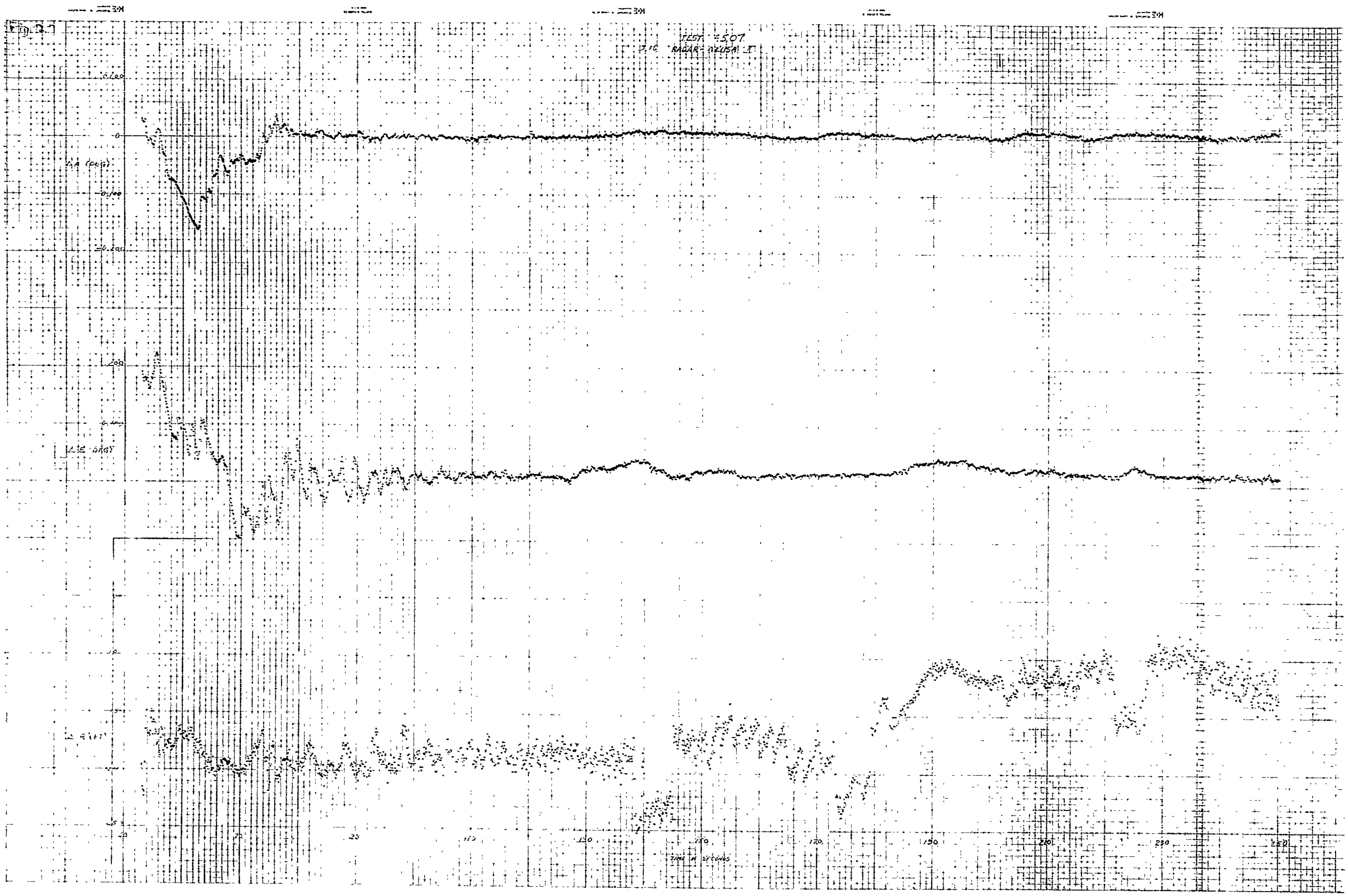

TEST 507
TIME IN SECONDS

FIG. 28

Power Spectrum of Radar - Azusa Mk 2

Azimuth Differences

Test No: 4507
Radar No : 3.16

No. of Points: N=10/sec.
Max. Lag : M=120 points
Time Span : 50 - 250 sec.

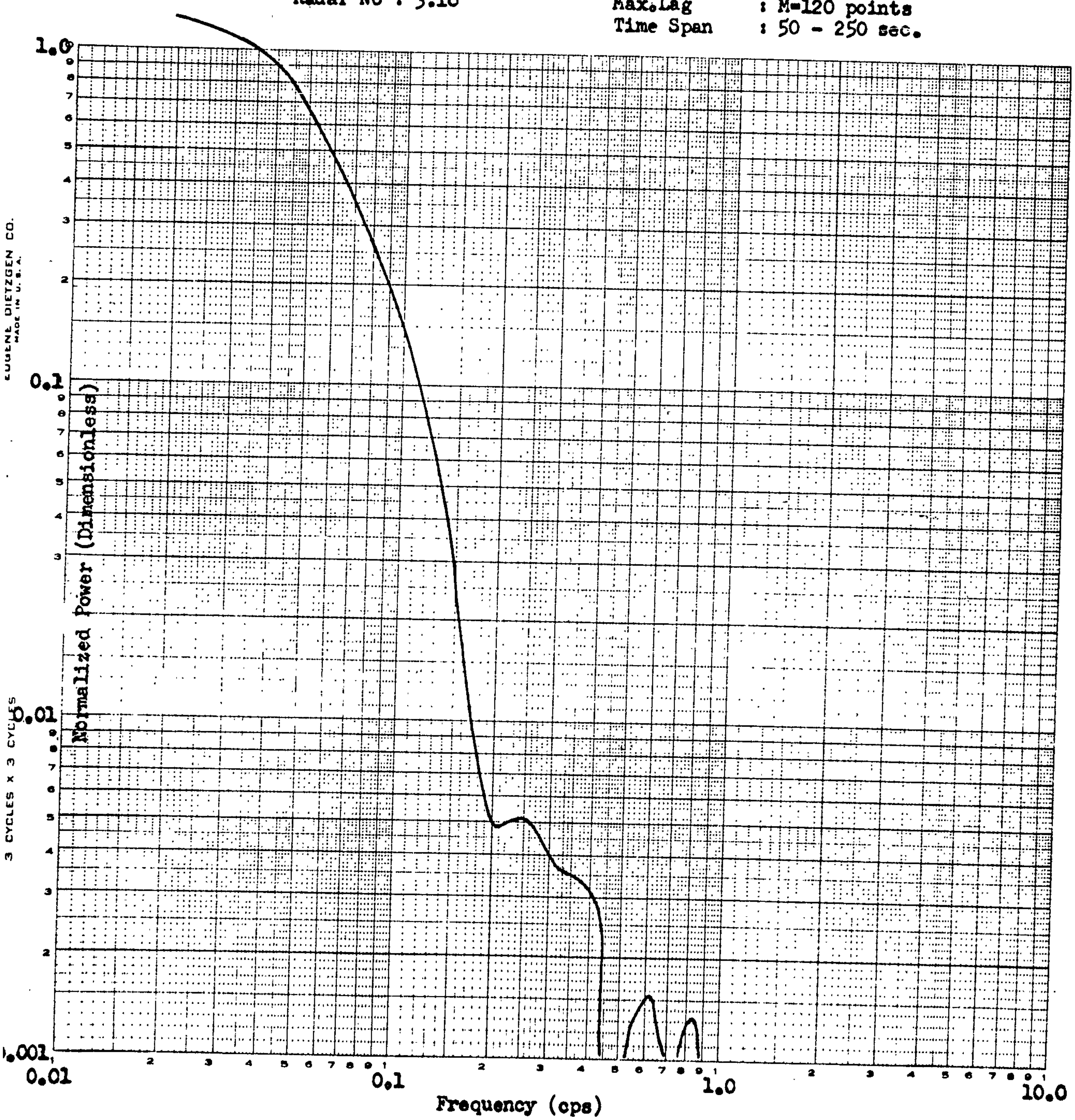


FIG. 29

Power Spectrum of Radar - Azusa Mk 2
Elevation Differences

Test No:4507
Radar No:3.16

No. of Points: N=10/sec.
Max. Lag : M=120 points
Time Span : 50-250 sec.

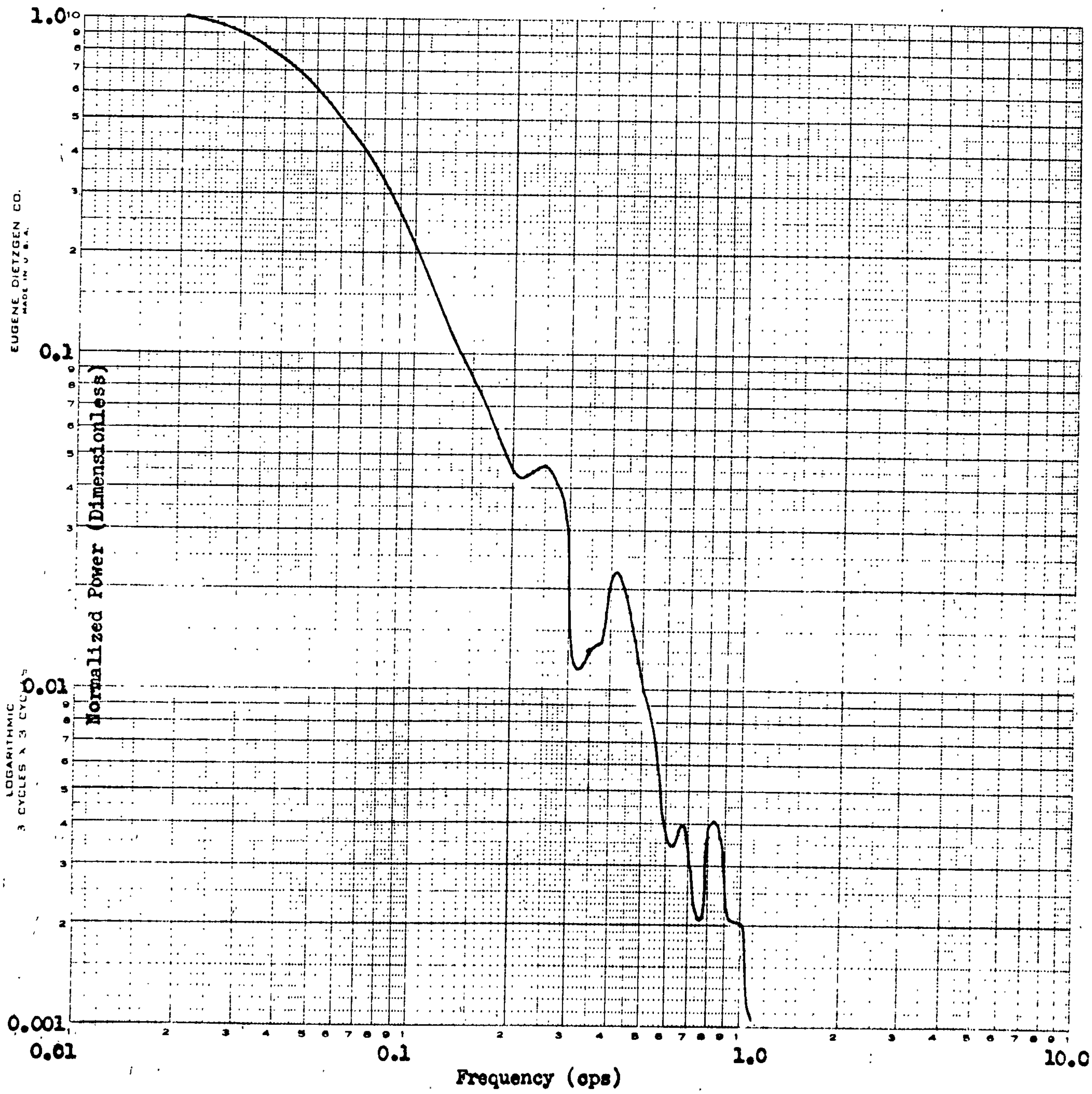
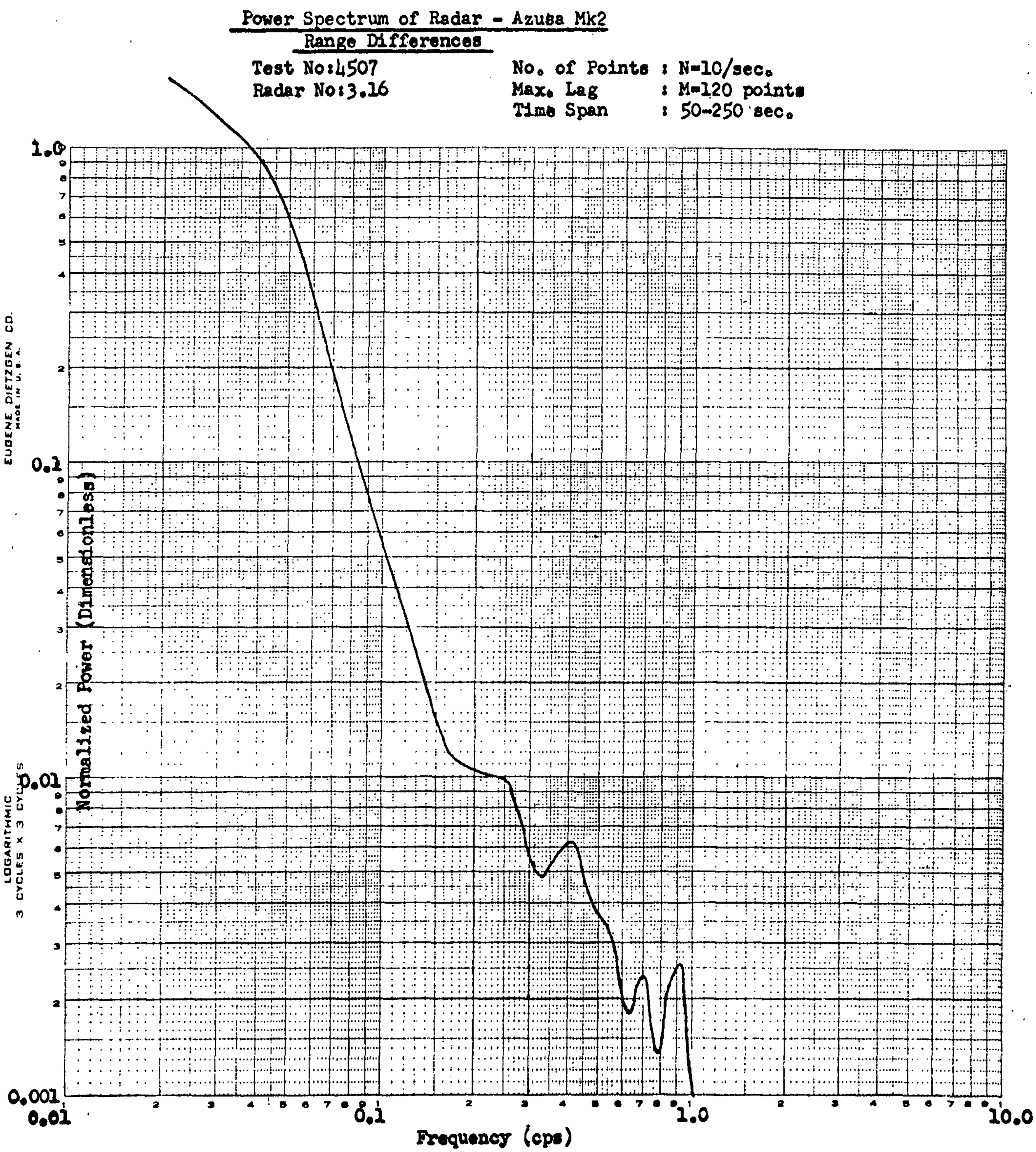


FIG. 30


Power Spectrum of Radar - Azusa Mk2
Range Differences
Test No:4507
Radar No:3.16
No. of Points : N=10/sec.
Max. Lag : M=120 points
Time Span : 50-250 sec.
1.0
0.1
0.01
0.001
Normalized Power (Dimensionless)
0.01
0.1
1.0
10.0
Frequency (cps)
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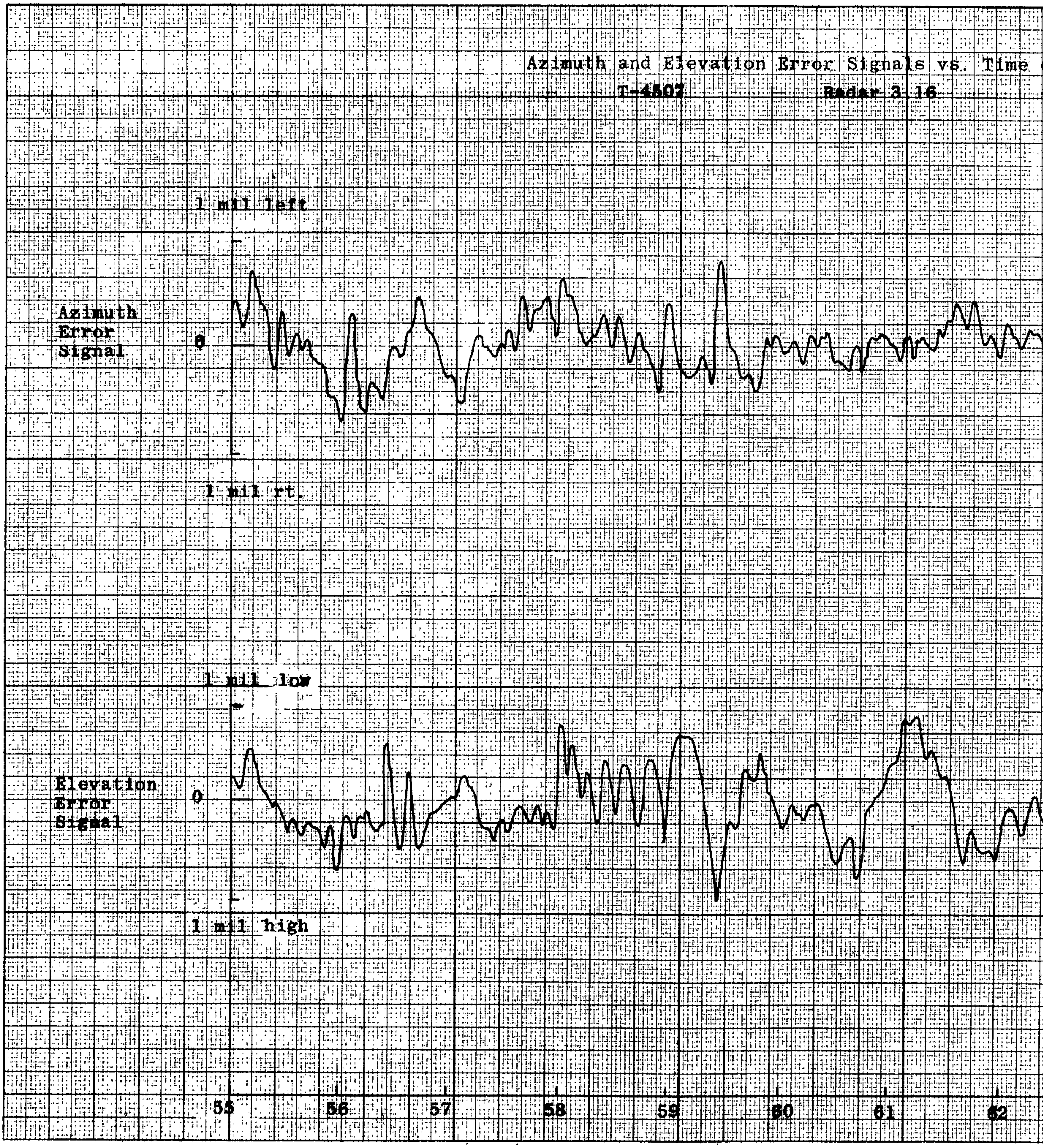
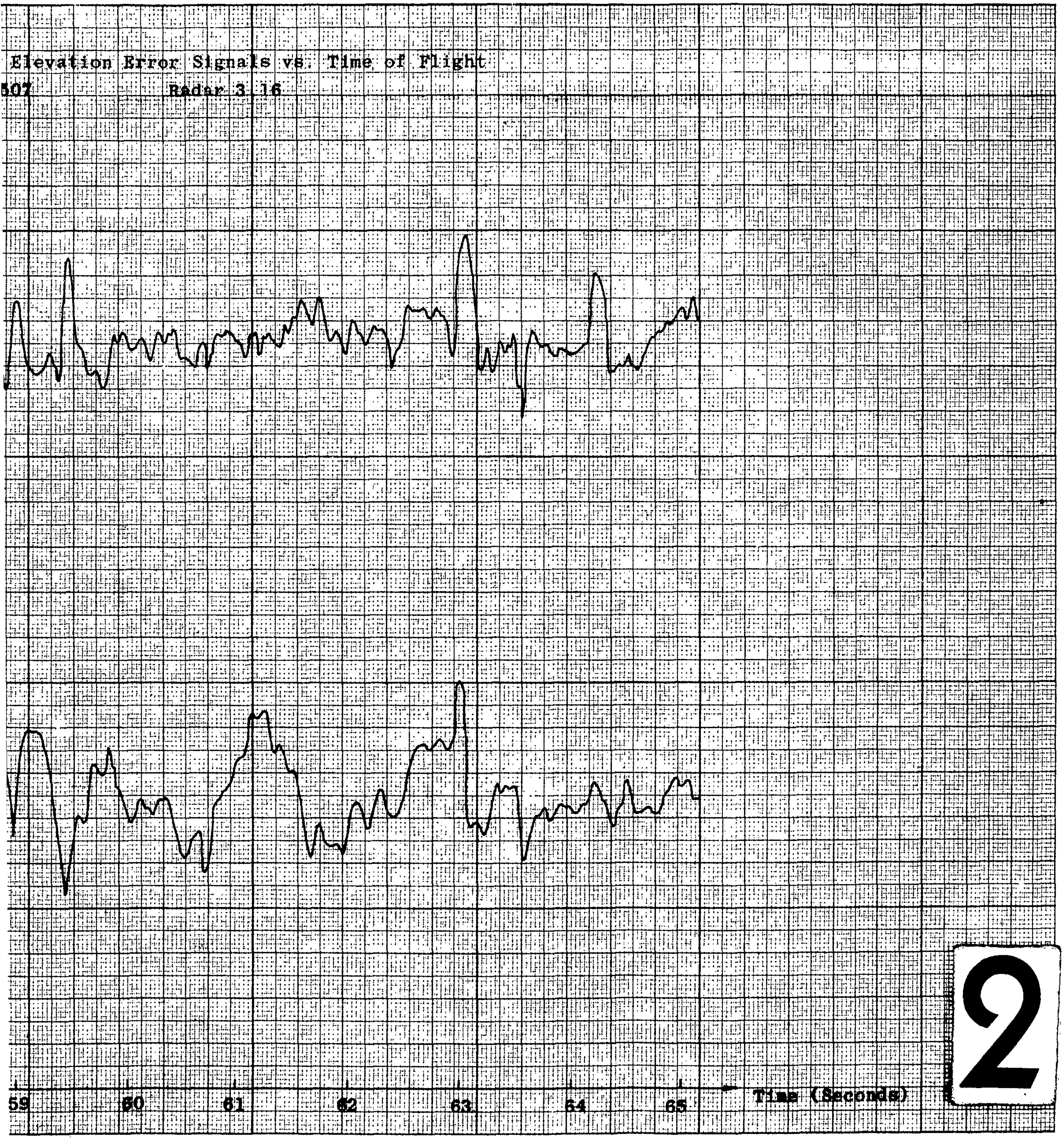


Azimuth and Elevation Error Signals vs. Time o
T-4507
Radar 3.16
1 mil left
Azimuth
Error
Signal
0
1 mil rt.
1 mil low
Elevation
Error
Signal
0
1 mil high
55
56
57
58
59
60
61
62

FIG.31


Elevation Error Signals vs. Time of Flight
507
Radar 3 16
59
60
61
62
63
64
65
Time (Seconds)

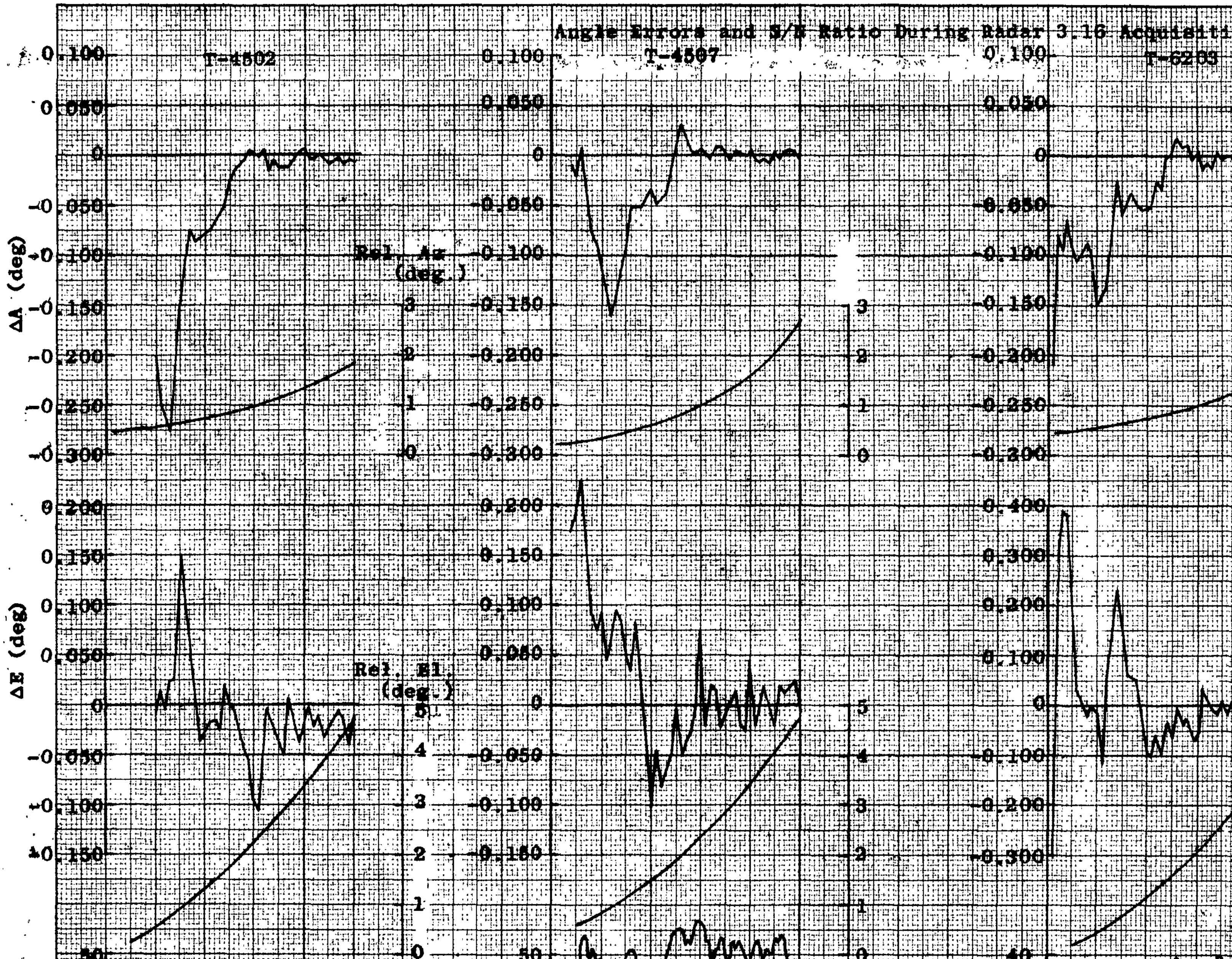
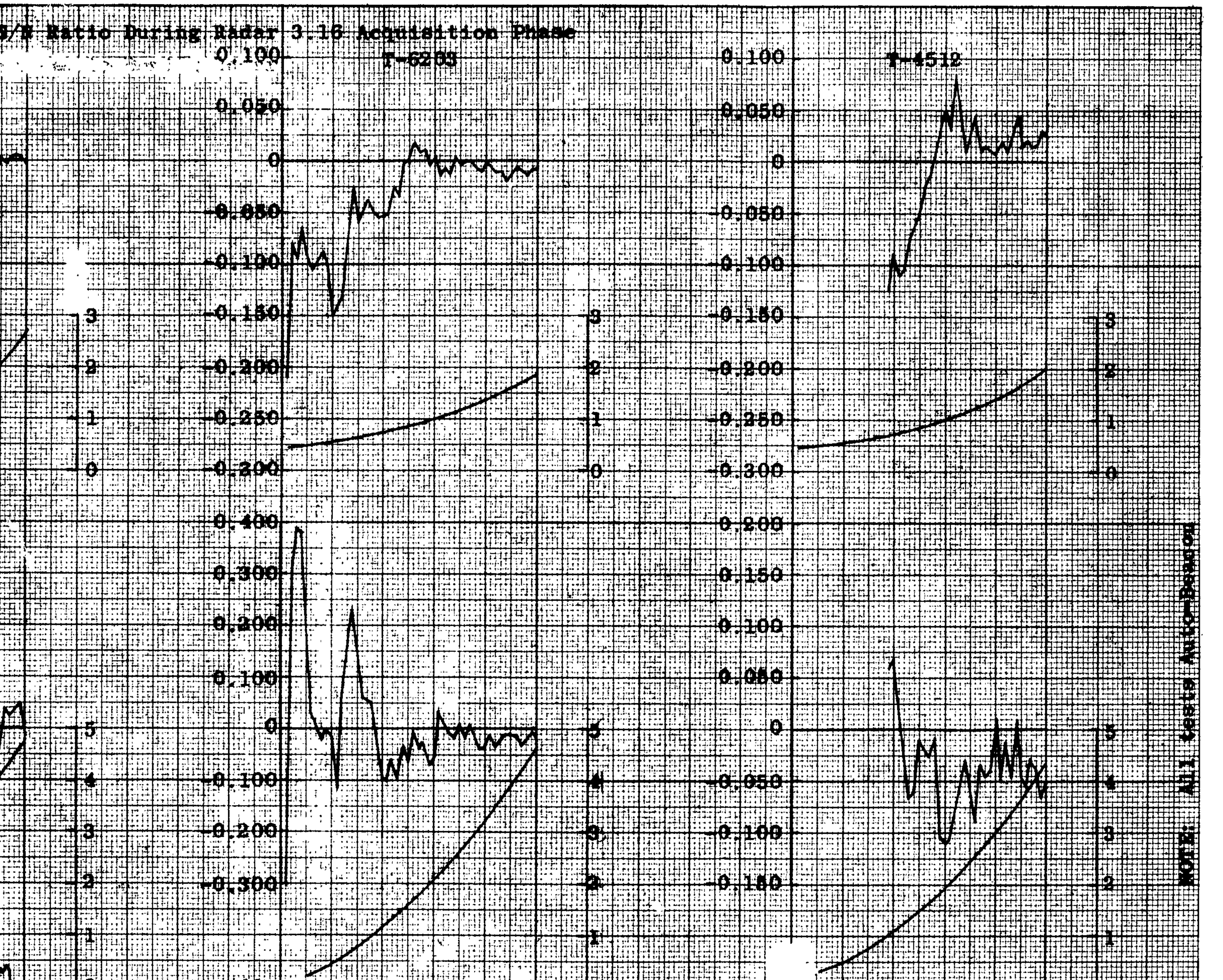

Angle Errors and S/N Ratio During Radar 3.16 Acquisiti
T-4502
T-4507
T-6203
ΔA (deg)
ΔE (deg)
S/N (db)
Rel. Az
(deg.)
Rel. El.
(deg.)
0.100
0.050
0
-0.050
-0.100
-0.150
-0.200
-0.250
-0.300
0.200
0.150
0.100
0.050
0
-0.050
-0.100
-0.150
0.400
0.300
0.200
0.100
0
-0.100
-0.200
-0.300
50
40
30
20
50 60 70 80 90 100

FIG. 32


S/N Ratio During Radar 3.16 Acquisition Phase
T-6203
T-4512
NOTE: All tests Auto-Beacon

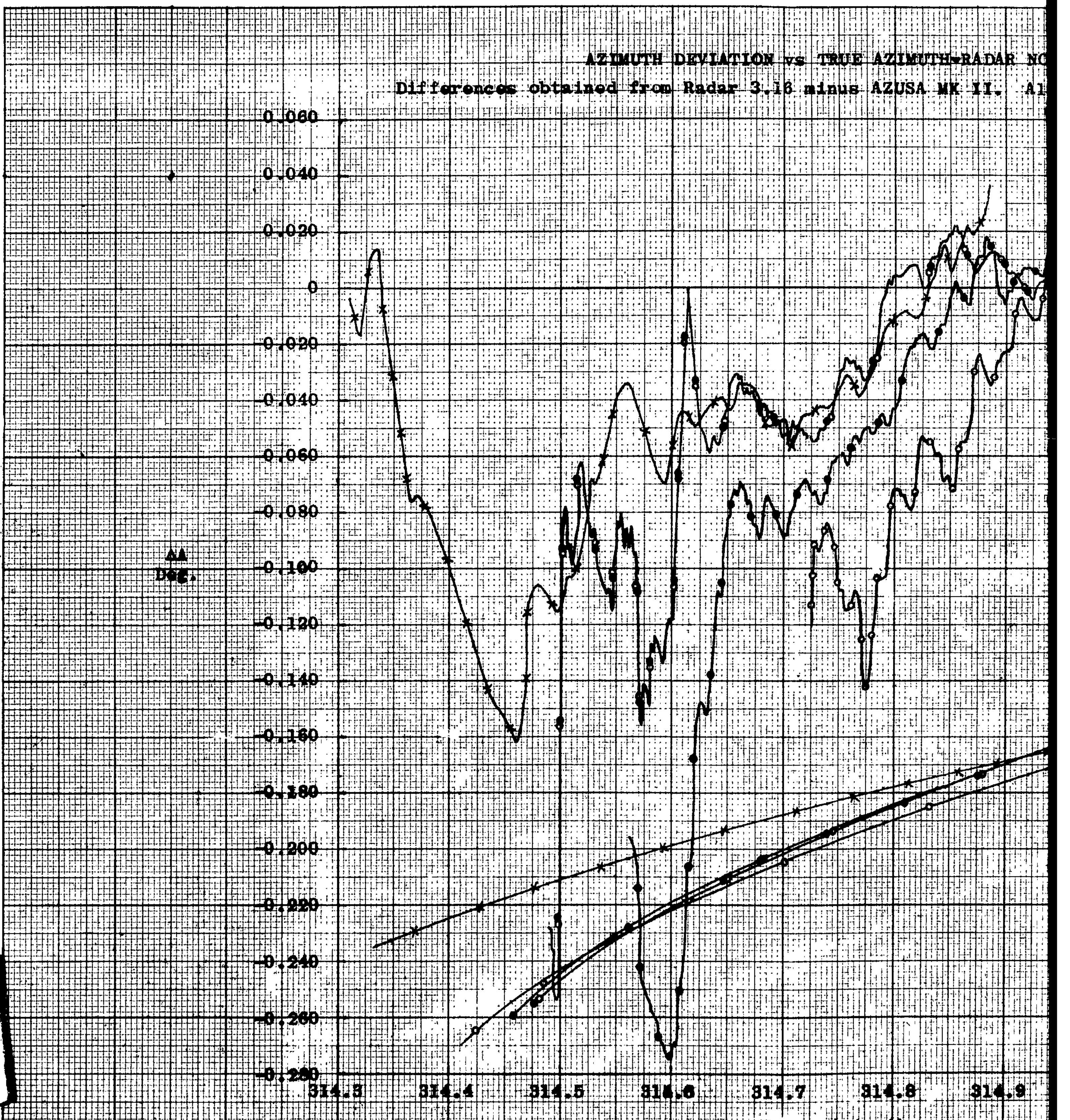

AZIMUTH DEVIATION vs TRUE AZIMUTH-RADAR NO
Differences obtained from Radar 3.16 minus AZUSA MK II.
ΔA Deg.
0.060
0.040
0.020
0
-0.020
-0.040
-0.060
-0.080
-0.100
-0.120
-0.140
-0.160
-0.180
-0.200
-0.220
-0.240
-0.260
-0.280
314.3
314.4
314.5
314.6
314.7
314.8
314.9
True Azimuth

FIG. 33

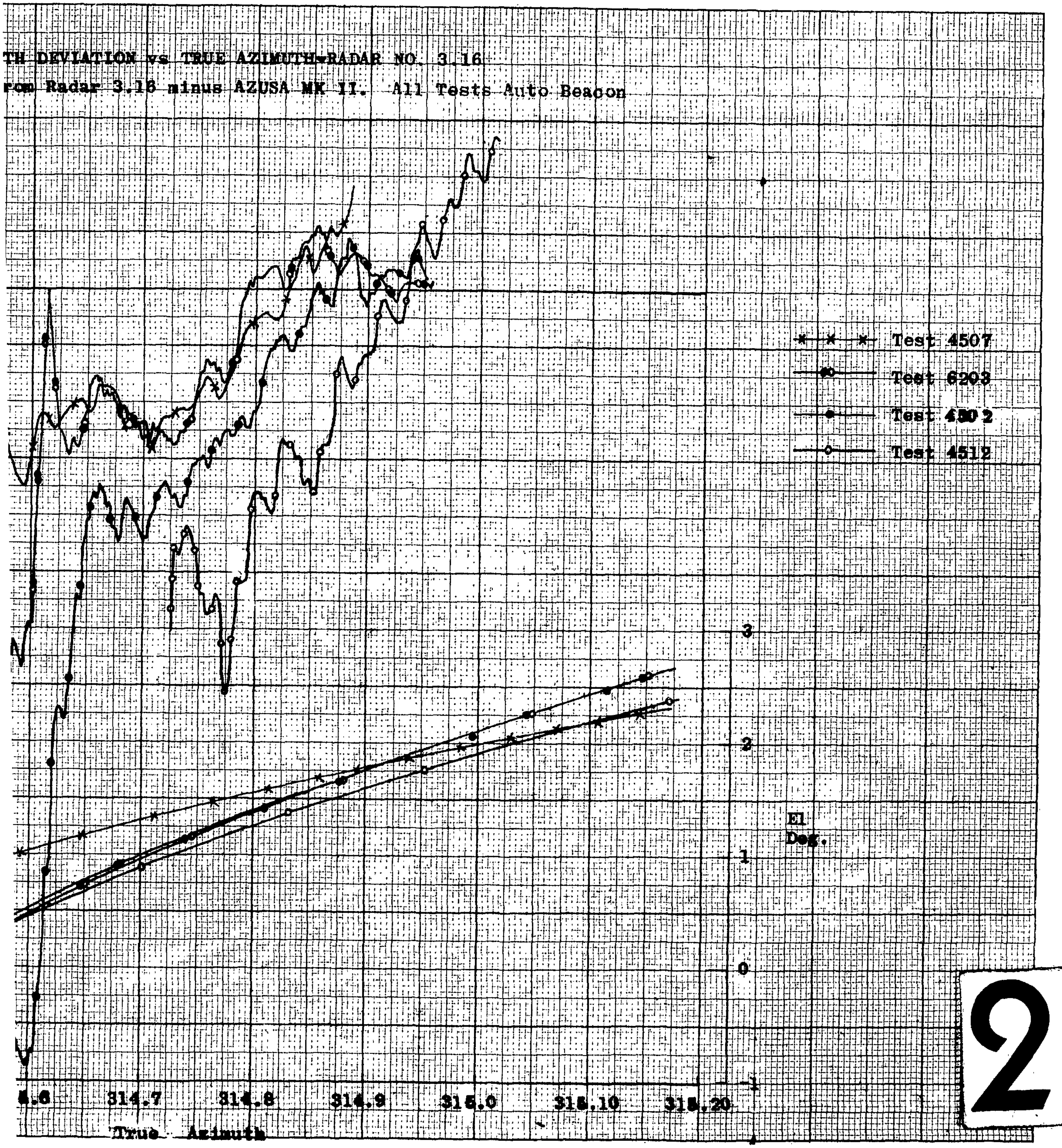
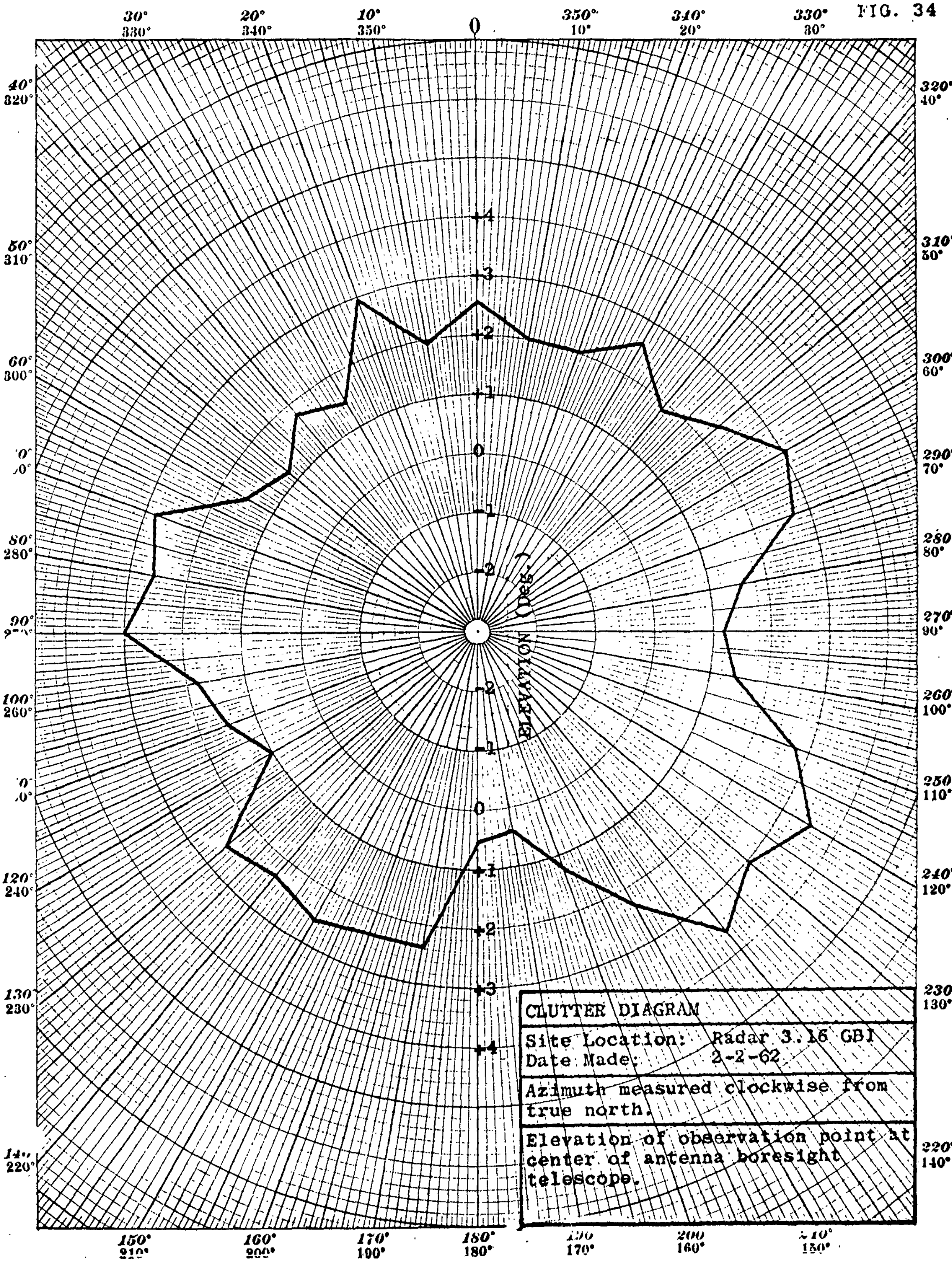

TH DEVIATION vs TRUE AZIMUTH-RADAR NO. 3.16
rom Radar 3.16 minus AZUSA MK II. All Tests Auto Beacon
Test 4507
Test 6203
Test 4502
Test 4512
El
Deg.
3
2
1
0
-1
4.6
314.7
314.8
314.9
315.0
315.10
315.20
True Azimuth
2

FIG. 34



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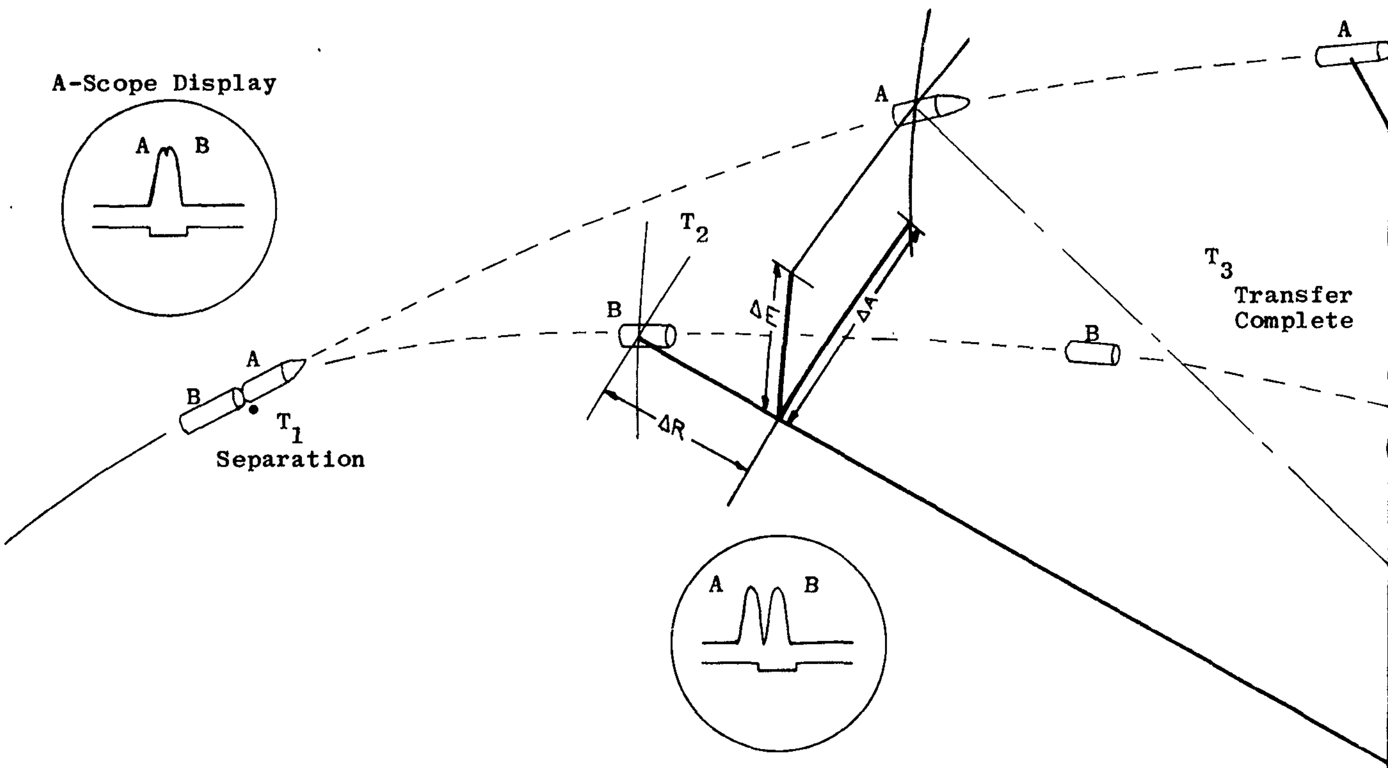
TRACKING GEOMETRY AND RADAR OPERATION ON SEPARATING TARGE

(Typical for Radar 3.16 track during T-120)



1

TRANSFER EVENTS:

T_1 After separation, second stage A (carrying the AZUSA transponder) continues to accelerate and leads 1st stage (B). Radar is unable to resolve target echoes and stays locked to 1st stage, causing increasing differences between time-coincident radar and AZUSA position measurements.

T_2 Increasing relative distance between 1st and 2nd stage causes 2nd to appear off-set in Azimuth and Elevation and closer in Range relative to the radar. Radial difference between target echoes becomes sufficiently large for unambiguous transfer of radar track to 2nd stage echo.

T_3 Radar track gate is shifted to second stage echo. Radar range and angle measurements are referenced accordingly, and the differences between radar and AZUSA position data are now minimized.

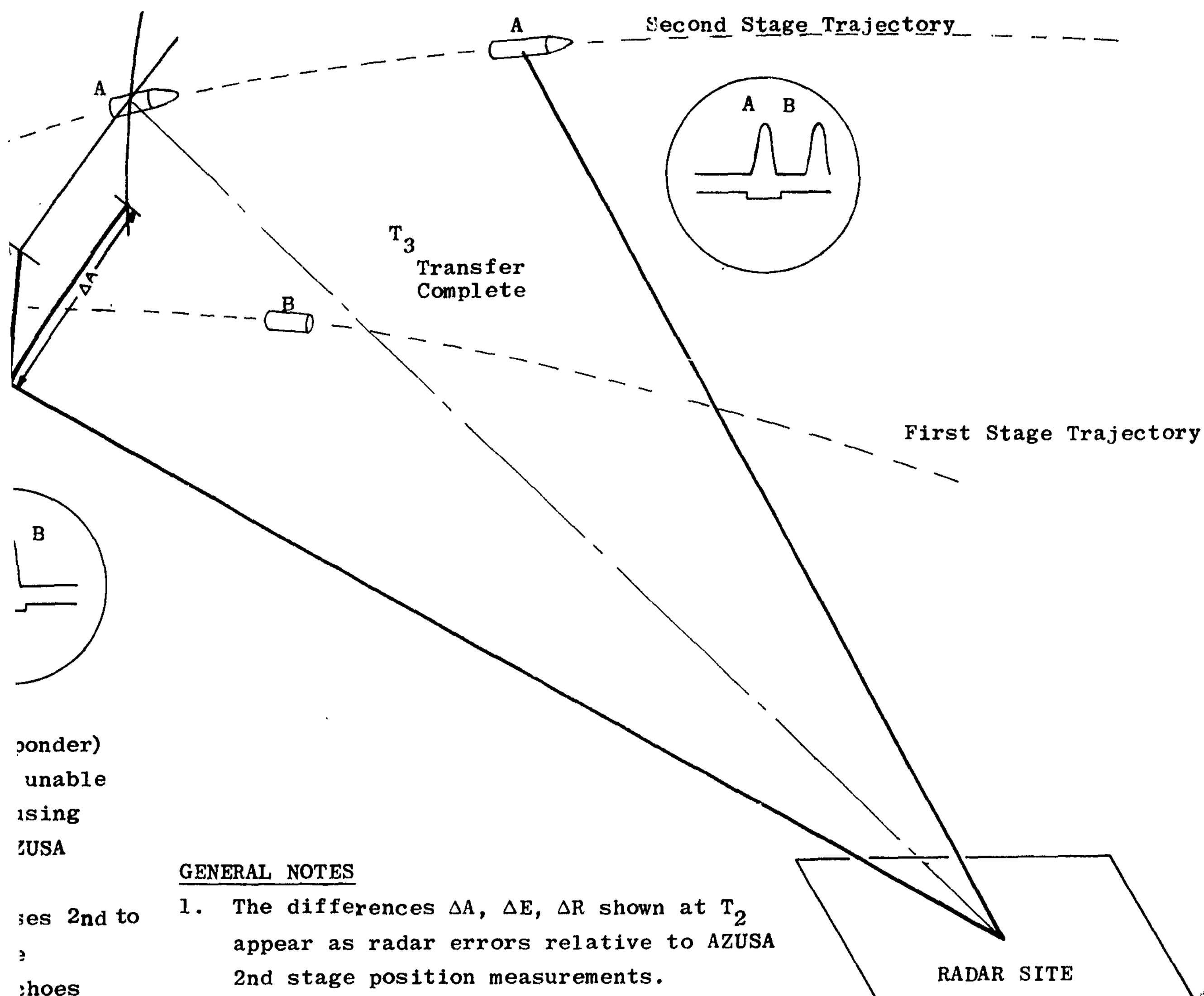
GENERAL NOTES

1. The differences ΔA, ΔE, appear as radar errors r 2nd stage position measu
2. The A-scope displays rep as observed by the radar
3. Drawing not to scale.

FIG. 35

'(AND RADAR OPERATION ON SEPARATING TARGETS (ECHO TRACK)

'ypical for Radar 3.16 track during T-120)



ponder)
unable
ising
ZUSA

ses 2nd to

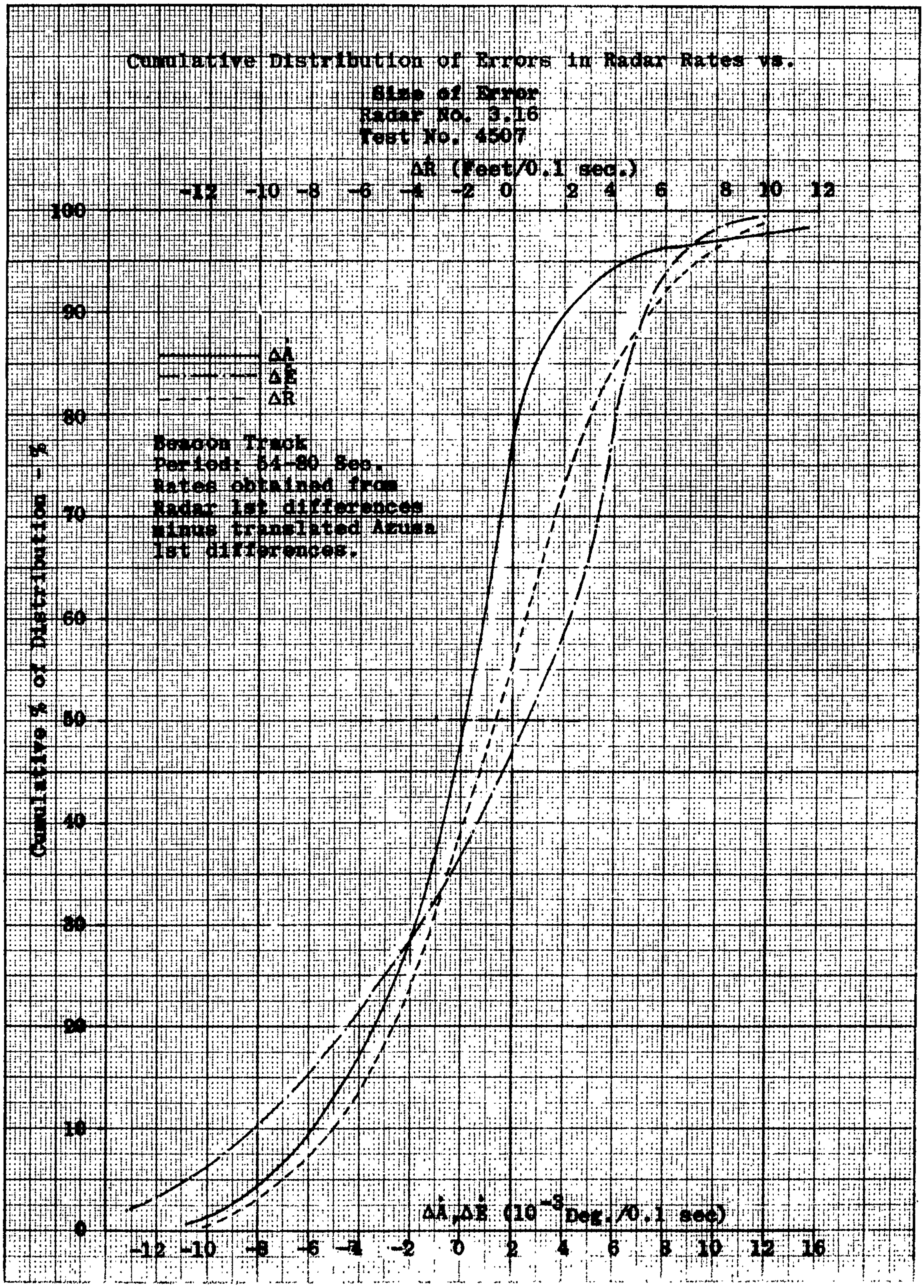
choes
ır track

ınge and
'erences

GENERAL NOTES

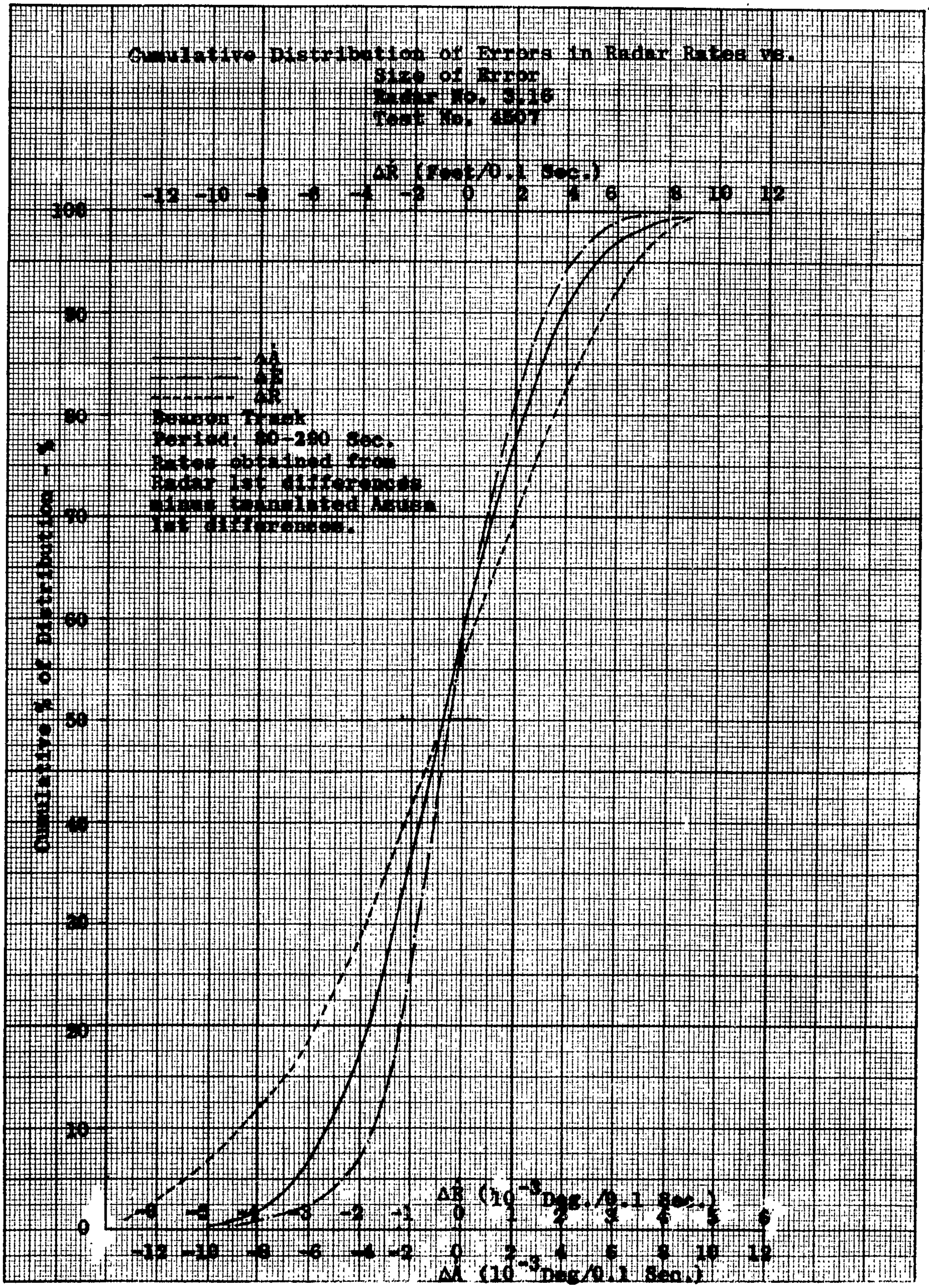
1. The differences ΔA, ΔE, ΔR shown at T_2 appear as radar errors relative to AZUSA 2nd stage position measurements.
2. The A-scope displays represent radar video as observed by the radar site operator.
3. Drawing not to scale.

FIG. 36



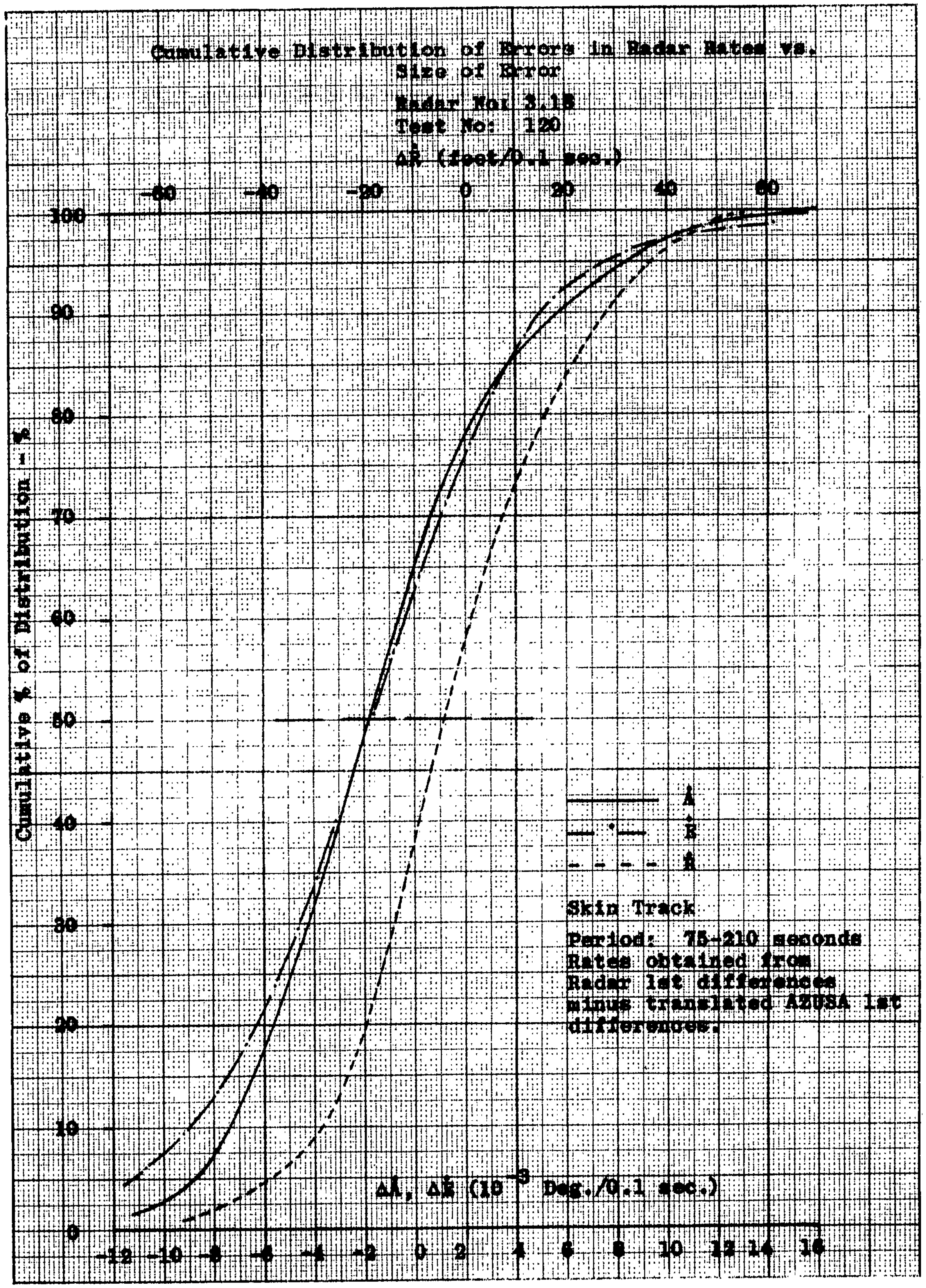
Cumulative Distribution of Errors in Radar Rates vs.
Size of Error
Radar No. 3.16
Test No. 4507
ΔṘ (Feet/0.1 sec.)
-12 -10 -8 -6 -4 -2 0 2 4 6 8 10 12
100
90
80
70
60
50
40
30
20
10
0
ΔȦ
ΔĖ
ΔṘ
Beacon Track
Period: 64-80 Sec.
Rates obtained from
Radar 1st differences
minus translated Azusa
1st differences.
Cumulative % of Distribution - %
ΔȦ, ΔĖ (10^-3 Deg./0.1 sec)
-12 -10 -8 -6 -4 -2 0 2 4 6 8 10 12 16

FIG. 37



Cumulative Distribution of Errors in Radar Rates vs.
Size of Error
Radar No. 3.16
Test No. 4507
$\Delta\dot{R}$ (Feet/0.1 Sec.)
$\Delta\dot{A}$
$\Delta\dot{E}$
$\Delta\dot{R}$
Beacon Track
Rates obtained from
Radar 1st differences
minus translated Askania
1st differences.
Cumulative % of Distribution - %
$\Delta\dot{E}$ (10^{-3} Deg./0.1 Sec.)
$\Delta\dot{A}$ (10^{-3} Deg/0.1 Sec.)

FIG.38



Cumulative Distribution of Errors in Radar Rates vs.
Size of Error
Radar No: 3.18
Test No: 120
ΔṘ (feet/0.1 sec.)
-60 -40 -20 0 20 40 60
100 90 80 70 60 50 40 30 20 10 0
Cumulative % of Distribution - %
Ȧ
Ė
Ṙ
Skin Track
Period: 75-210 seconds
Rates obtained from
Radar 1st differences
minus translated AZUSA 1st
differences.
ΔȦ, ΔĖ (10^-3 Deg./0.1 sec.)
-12 -10 -8 -6 -4 -2 0 2 4 6 8 10 12 14 16

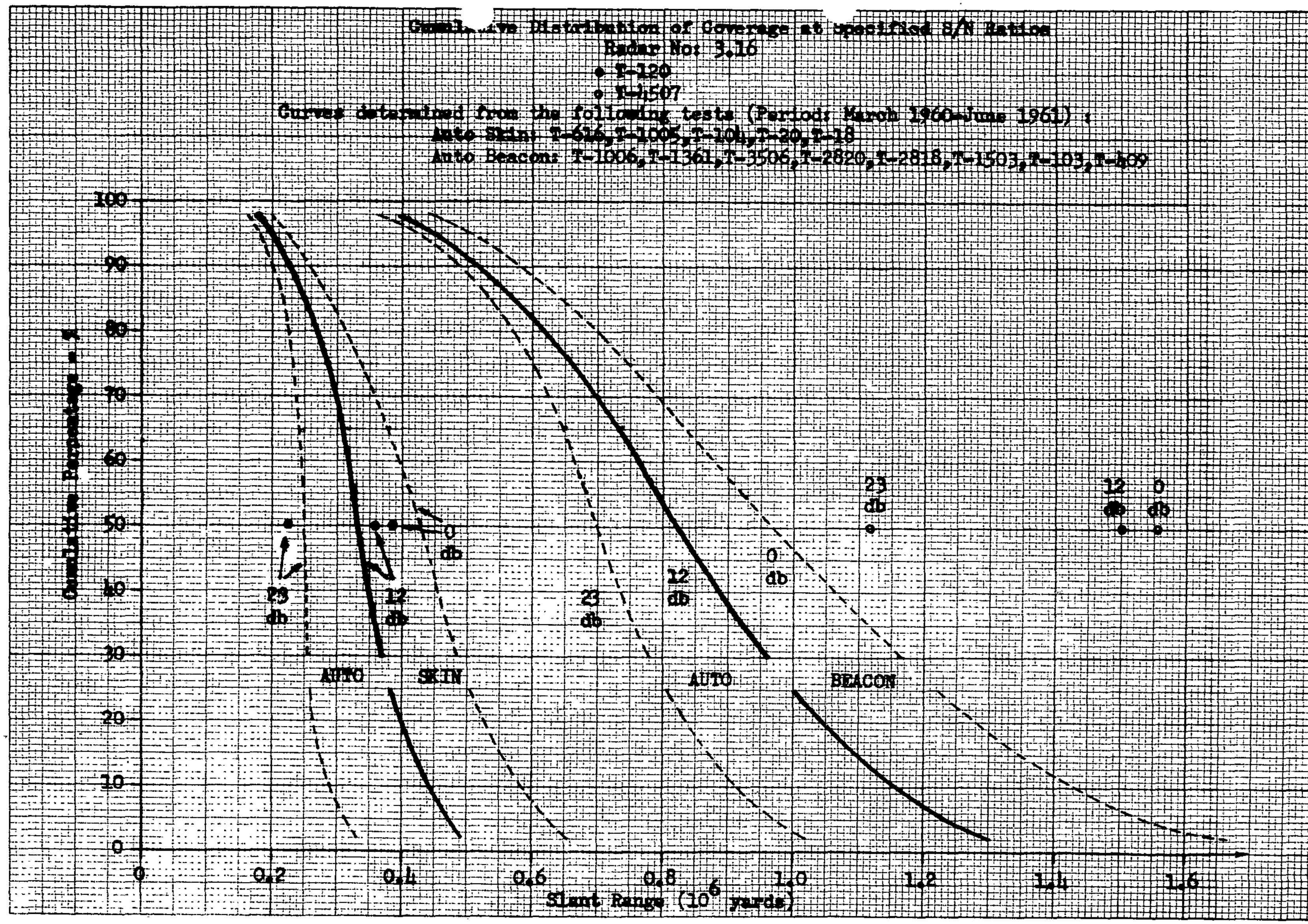

Cumul...ive Distribution of Coverage at Specified S/N Ratios
Radar No: 3.16
• T-120
∘ T-4507
Curves determined from the following tests (Period: March 1960-June 1961) :
Auto Skin: T-616,T-1005,T-104,T-20,T-18
Auto Beacon: T-1006,T-1361,T-3506,T-2820,T-2818,T-1503,T-103,T-409
Cumulative Percentage = %
Slant Range (10^6 yards)
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
10
20
30
40
50
60
70
80
90
100
23 db
12 db
0 db
AUTO
SKIN
BEACON

FIG. 39

REFERENCES

1. Ltr. RCA Systems Analysis to Operations Control, PAA, GMRD, 28 July 1961, subject "AN/FPS-16 Evaluation," w/incl: RADAR EVALUATION PLAN.

2. Final Report "INSTRUMENTATION RADAR AN/FPS-16 (XN-2)," RCA Defense Electronics Products (Moorestown), Contract DA36-034-ORD-151 (distributed in March 1959)

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Rpt. No. MTC-TDR-63-
RADAR 3.16 ACCURACY EVALUATION (U). Final Report, Aug. 62
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1. Radar Tracking
2. Radar Equipment
3. Error Analysis

I. W/O 300001
II. Contract AF 08(606)-5300
III. RCA Svc Co., Subcontr of PAA World Airways, Inc., Patrick AFB, Fla.
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